AD-759 002

INTERNAL BLAST DAMAGE MECHANISMS COMPUTER PROGRAM

James F. Proctor

Naval Ordnance Laboratory

Prepared for:

Air Force Flight Dynamics Laboratory

31 August 1972

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NOLTR 72-231

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31 AUGUST 1972

NOL

NAVAL ORDNANCE LABORATORY, WHITE OAK, SILVER SPRING, MARYLAND

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NOLTR 72-231

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Ordnance Laboratory Silver Spring, Maryland 20910	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
Internal Blast Damage Mechanisms Computer Program

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report, June 1971 to February 1972

5. AUTHOR(S) (First name, middle initial, last name)
James F. Proctor

6. REPORT DATE 31 August 1972	7a. TOTAL NO. OF PAGES ~~116~~ 114	7b. NO. OF REFS 22

8a. CONTRACT OR GRANT NO. MIPR No. F1456-71-00011 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NOLTR 72-231 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) 61 JTCG/ME-73-3

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Air Force Systems Command Air Force Flight Dynamics Laboratory Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

A computer program has been developed at NOL that describes the shock and blast loading characteristics of the detonation of a high explosive projectile internal to an aircraft structure; both shock wave and confined-explosion gas pressure loads are considered. With certain modifications, the program can be made applicable to any internal explosion irrespective of the type of confining configuration, e.g., a naval ship compartment, land vehicle, or building structure.. Discussions are given on the general use and content of the program, the input options available in the code, and the technical aspects of the calculational methods used to determine shock loading functions, confined-explosion gas pressure, venting of the confined gases, and damage propagation to other areas of the aircraft. Comparisons of code results with available experimental data are presented to demonstrate the justifiable confidence in the use of the code on aircraft problems. Complete documentation of the code is given together with results of sample problems that show the various features of the code and the readily usable form of the resultant loading information.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Explosion, internal Confined Explosion Explosive Effects Explosion Computer Code Projectile Damage Aircraft Vulnerability Internal Blast						

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NOLTR 72-231 31 August 1972

Internal Blast Damage Mechanisms Computer Program

The work described in this report was performed under NOL Task 594/W-PAFB, Internal Blast Mechanisms under the sponsorship of the Survivability-Vulnerability Branch, Prototype Division, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB (MIPR FY1456-71-00011). The objective of this task was to develop a computer program for describing blast characteristics associated with the detonation of a high explosive projectile internal to an aircraft structure. It is expected that this program will become an item in the component damage data bank under development by the Aerial Target Vulnerability Program of the Joint Technical Coordinating Group for Munitions Effectiveness.

The author wishes to acknowledge the able assistance received from his fellow staff workers, T. O. Anderson, W. S. Filler, D. Lehto, and C. Richmond, in the technical development of the computational methods used in this program. A particular debt of gratitude is owed to Mr. Lehto who programmed this code and assisted in the preparation of the user's guide in Chapter 7 and the attached appendices.

This report is also available as 61 JTCG/ME-73-3.

ROBERT WILLIAMSON II
Captain, USN
Commander

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C. J. ARONSON
By direction

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SUMMARY AND CONCLUSIONS

Assessment of damage to aircraft structures from the detonation of explosive projectiles internal to the aircraft requires a detailed knowledge of the dynamic pressure loads applied to various structural elements. NOL has developed a computer program that is capable of generating characteristic blast loading parameters associated with confined explosions in a form readily usable by aircraft design engineers and vulnerability analysts. Existing state-of-the-art explosion theory and experimental data were used as the basis for the shock wave calculations available in the code. An improved method of predicting the confined-explosion gas pressure that exists after shock dissipation was developed especially for this code. Any size explosion can be treated by the code for any ambient altitude condition up to and above 50,000 ft, and the code includes the blast properties of some 29 different explosives including mono, composite, and aluminized varieties.

The computer program analytically divides the internal explosion into two damaging mechanisms--the shock wave and the confined-explosion gas pressure. For the shock wave it generates the incident and normally reflected pressure-time histories and impulses for the positive phase duration at a specified distance from the explosion. Existing data and theory were used to develop the shock calculational model. The code reduces the shock calculation for all cases to the reference data from a free-field, bare, spherical 1-lb TNT explosion. Variables that affect airblast which are included in the code for establishing an equivalent TNT spherical explosion are (1) explosive weight, (2) type of explosive, (3) cylindrical charge geometry, (4) case weight of the projectile, and (5) ambient pressure and temperature at the location in the aircraft where the explosion occurs.

For an explosion internal to a confining structure or compartment, a long-duration quasi-static pressure exists after dissipation of the shock wave. The maximum value of the pressure, defined as the confined-explosion gas pressure, is dependent on these parameters; (1) weight of explosive, (2) type of explosive (chemical composition), (3) volume of compartment, and (4) pressure and temperature of the air initially in the compartment. Because of the inadequacies of existing methods of calculating the confined-explosion gas pressure, a technique was developed especially for this program that follows the energy generation of the chemical reactions and the changes in gas properties as the confined-explosion gas pressure is developed. In a completely closed compartment or structure, heat loss to the surrounding walls is the only mechanism for reducing the pressure in time, but this phenomenon is neglected in this program because of the very long durations involved. However, for the aircraft structure, there will be openings or vent areas through which the confined gases can escape such as the initial opening due to entry of the projectile into the compartment and any fragment penetration openings. Also the pressure can change abruptly due to wall failure of the compartment which introduces a new compartment volume. The computer program calculates the variation of the confined-explosion gas pressure with time for venting and such volume changes. Vent area and volume changes are controlled by input damage criteria for compartment wall failure.

In addition to the technical description of the calculational models contained in the computer program, a user's guide and complete documentation of the code are given in the text of the report and the attached appendices. Also nine sample problems are presented that demonstrate the many options and features of the program.

Although no single set of experimental data was available to compare with the overall code performance, each individual calculational model was tested against pertinent experimental data. Sufficient shock and confined-explosion gas pressure data were found for comparison, and the agreement with code predictions in these cases was excellent. It is concluded that the calculational models

for these most important aspects of the internal blast loading can be used with justifiable confidence. Whereas the pressure-time decay of the confined-explosion gas pressure due to venting has been verified with limited data, the introduction of volume changes has not been tested. The method for treating instantaneous volume changes is based on fundamental thermodynamic relations, thus there is no reason to believe that this section of the calculation detracts from the use of the code for general aircraft internal blast problems.

The computer program has wide range potential for use in studies of structural response of any military or civilian system to an internal explosion be it aircraft, naval ship, land vehicle, or building structure. Although it is adequate for the aircraft problems for which it is presently designed, there are five areas in the code that require additional study and possible modifications before its generality can be claimed for large explosions in large structure compartments such as ship compartments and building rooms. These are (1) multiple shock reflections from surrounding walls, (2) heat losses to surrounding walls that might reduce the confined-explosion gas pressure to a significant degree for large structures, (3) variable backpressure to the venting process, (4) gas pressure-time history where mixing of gases after wall failure occurs in a finite time interval, and (5) subsequent chemical reactions with the air in adjacent compartments after wall failure if complete combustion is not achieved in the initial compartment. With modification to the code reflecting the above suggested studies, it is believed this computer code could evolve as a general service-wide tool for the investigations of structural response to internal explosion loading.

CHAPTER 1

INTRODUCTION

One of the current ongoing tasks of the Aerial Target Vulnerability (ATV) Program of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) has been the development of a component damage data bank. An item defined in this data bank is the vulnerability of aircraft to internal blast from high explosive projectiles. Under the direction of the Survivability-Vulnerability Branch, Prototype Division, Air Force Flight Dynamics Laboratory (AFFDL), the objectives of this task are (1) to define the internal blast loading characteristics from a high-explosive projectile, (2) to determine the damage to aircraft structures, and (3) to assess the vulnerability of these structures to internal blast effects. The Naval Ordnance Laboratory (NOL) was assigned the technical solution of the first task problem area, namely, to define the internal blast loading characteristics.

Specifically, the objective of the NOL program was to develop mathematical and graphical techniques for describing blast characteristics associated with the detonation of a high explosive projectile internal to an aircraft structure. Existing state-of-the art experimental data and explosion theory were to be combined using sound engineering judgment to provide a computer program capable of generating characteristic shock wave and blast loading from an explosion internal to an aircraft. Execution of the computer program and the resultant loading functions were to be in a form readily usable by aircraft design engineers and vulnerability analysts.

Although this task was directed to the solution of the aircraft problem, the concepts, content, and format of the resultant computer code can be related to any military or civilian system be it aircraft, naval ship, land vehicle, or building structure. The code was structured to accommodate easy modification for any new system.

With usage on response problems for structures other than aircraft, it is hoped that a more complete internal blast loading computer program will evolve for general use.

CHAPTER 2

GENERAL DESCRIPTION AND LIMITATIONS OF COMPUTER PROGRAM

Assume that a high explosive is detonated in a closed structure of some arbitrary geometry with a small vent opening. If a pressure sensor were to be placed on the wall of the structure, it would indicate a pressure-time history of the type shown in Figures 2.1(a) and (b). On an expanded time scale (a), one would note the initial peak reflected shock overpressure, ΔP_r, followed by subsequent reflected shock pulses from the adjacent confining wall of the structure. The oscillations would dissipate leaving a quasi-static overpressure, ΔP_g, created by the heated gases contained in the structure; this pressure is defined as the confined-explosion gas pressure. On a reduced time scale (b), the shock reflections would appear as high spikes near time zero. The confined-explosion gas pressure, ΔP_g, would be clearly established on this time scale. Even for a completely closed structure, the gas pressure would slowly decrease in time due to heat losses to the surrounding structure walls. For a structure with some openings through which venting could occur, the gas pressure would decay much more rapidly.

An accurate description of the pressure-time history during the multiple reflected shock phenomena in a closed structure of arbitrary configuration was far beyond the scope of this program effort and economically beyond the scope of any three-dimensional hydrodynamic code. For this reason the shock wave calculations in this program are limited to the incident and normally reflected pressure-time shock, depicted in Figure 2.1 (c), arriving initially at a point on the structure wall. It is believed that the normally reflected pressure-time shock history and associated reflected impulse is sufficient to provide a meaningful index in determining the local structural response to shock wave loading. Further it is believed that the predominant damaging mechanism from an internal explosion

is the confined-explosion gas pressure. For most applications, the structure wall can be treated as though it were given an initial velocity by the shock wave as an initial boundary condition. Subsequent loading on the structure is defined by the confined-explosion gas pressure which is handled as a separate loading phenomenon completely decoupled from the shock wave.

The initial magnitude of the confined-explosion gas pressure is determined from a technique developed specifically for this program, which will be described in detail in a subsequent chapter. Relative to the slower plastic response time of a typical aircraft structure, it is assumed that the confined-explosion gas pressure, ΔP_g, depicted in Figure 2.1 (d) is developed instantaneously in time. In other words, the chemical reaction of the explosion gas products with the surrounding air in the initial confines of the structure and the heat transfer to the resultant gas mixture are assumed to occur instantaneously to develop the confined-explosion gas pressure. This pressure decreases in time due to venting through available openings created by the initial entry of the projectile into the structure, subsequent openings from fragment penetrations, and any normal structural openings such as cable passageways. Venting calculations assume a constant back pressure equal to atmospheric conditions outside the aircraft since most leakage would occur through fragment penetrations in the aircraft skin. Heat losses to the structure walls that could reduce the gas pressure are neglected because (1) significant heat loss would require times much larger than the plastic response times of the structures associated with the typical small aircraft compartments and (2) pressure decreases much more rapidly from venting through even the small projectile penetration opening than from heat losses.

Provisions are made to account for sudden changes in gas pressure due to structural failure resulting in rapid expansion into an adjacent compartment. It is assumed for these calculations that the change in pressure is instantaneous relative to the much slower plastic response times of the aircraft structures. Also in general the small compartment sizes in an aircraft structure would indicate a rapid stabilization of pressures if compartment walls failed.

In summary to this point, four assumptions have been made that may limit the use of this computer code to aircraft only. They are: (1) multiple shock reflections are neglected--only the initial shock serves as a damage index, (2) no variation in venting back pressure occurs, (3) heat losses to structure walls are neglected, and (4) instantaneous change in pressure occurs with compartment wall failure propagation. Whereas it is believed that these assumptions do not significantly restrict the study of aircraft response to internal blast, general application of this computer program directly to other structures, such as ships and buildings, may be hampered by these assumptions. Therefore, flexibility in code construction has been provided to allow for easy and efficient modification to those sections that would be affected by alterations to these assumptions.

The basis for this entire study was existing state-of-the-art theory, analytical methods, and experimental data for explosions. When directed to the problem of internal blast, these in themselves introduce limitations in terms of applicability, and some are open to interpretation even by explosion experts. Since the prime users of this code probably will not be people with background in explosion effects, all pertinent explosion properties are self-contained in the code. Only the type and amount of explosive are required as input to the code. In calculations where limitations arising from theory and data deficiencies are encountered, caution statements are clearly indicated in the output statements for the user's benefit.

The next four chapters present the technical aspects of the calculational methods contained in the code including theoretical and experimental background, certain operational procedures, and explanations of the more important features and options in the code. Comparisons of code predictions with available experimental data are also given in these sections. Chapter 7 and the attached appendices represent a user's guide or manual for the detailed content and operation of the code. Also a number of sample problems are included in this code documentation section to acquaint the user with the various options available in the code.

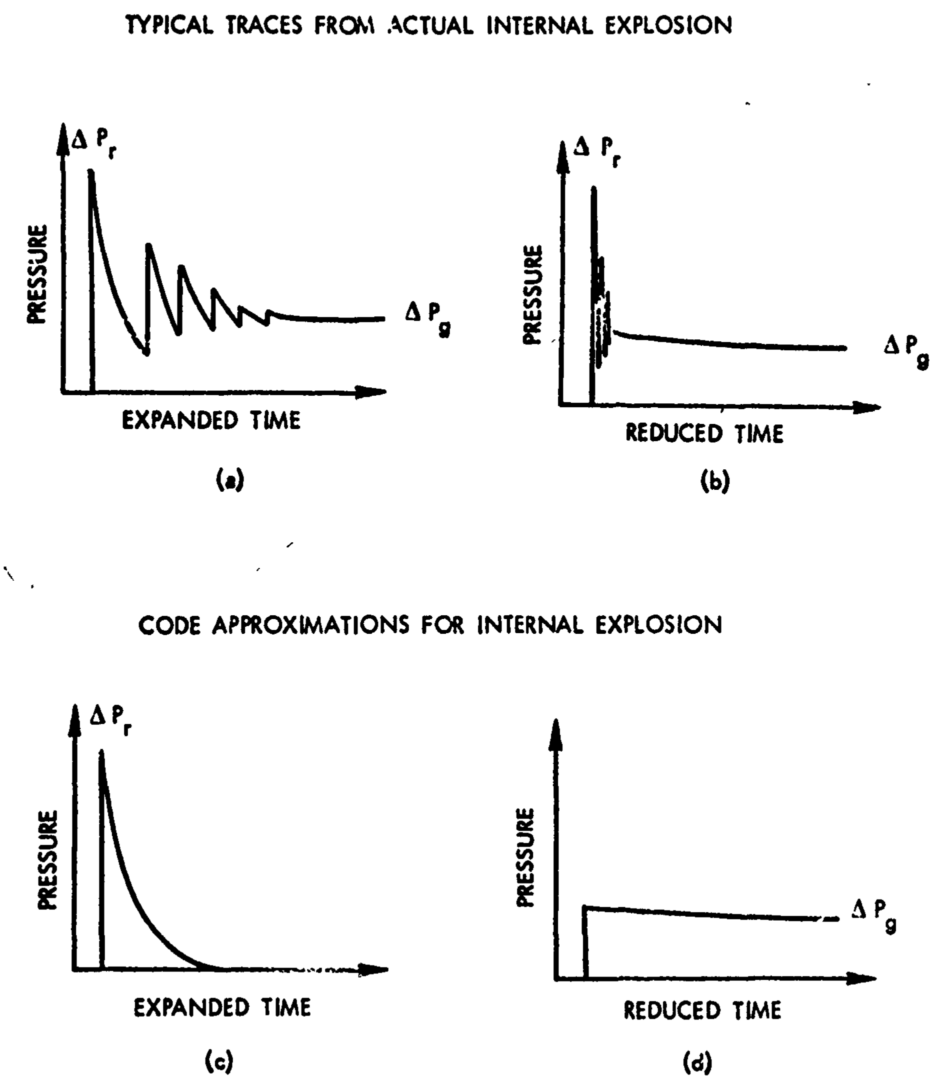


FIG. 2.1 TYPICAL PRESSURE-TIME CURVES FOR AN INTERNAL EXPLOSION

CHAPTER 3
INPUT DATA REQUIREMENTS

Explosive Parameters. For a typical high explosive projectile, only four of its properties are required as input to the computer program. They are: (1) weight of explosive, (2) type of explosive (3) length to diameter ratio of charge, and (4) metal case weight to charge weight ratio. Incorporated in the code are the pertinent properties of 24 types of explosives (Ref. (1)). Table 3.1 gives the coded properties of these 24 explosives plus 3 mono explosives that are rarely used alone as the main charge. The properties of aluminum and a common wax binder are also added. If the desired explosive is contained in this table, it is necessary only to input the index number to specify the explosive type. If one wishes to input an explosive not in the table, an index number of 0 is used and the required explosive properties must be specified. However, if for some reason the energy equivalent weight is not known, a zero for this quantity will permit shock calculations to be made with an equivalent weight of one--the same as for TNT. A diagnostic statement will appear in the output--"WFACT IS NOT KNOWN, 1.0 IS USED"--which means the shock calculations are equal to those for TNT. If the desired explosive is a mixture of components in Table 3.1, an index number of -1 is used and the weight fraction of each component must be specified. Again the energy equivalent weight may not be known, but it can be handled in the same manner as before by letting the equivalent weight equal zero. The only restriction on the type of explosive used in this program is that the explosive must be of C-H-N-O form with aluminum as the only possible metallic additive. It should be noted that this restriction arises from the confined-explosion gas pressure calculations; and as it will be discussed in subsequent chapters, this restriction has no obvious theoretical basis but must be invoked because of the lack of experimental data on other metallic additives or non-C-H-N-O explosives.

The computer program is capable of making corrections for cylindrical charge shape factors for length to diameter ratios (L/D) between 2 and 10. This is sufficiently general to accommodate most common anti-aircraft projectiles. If the L/D ratio is less than 2 as input, the code will treat the charge as spherical.

To account for effects of metal casing on the degradation of the shock wave, it is necessary to input the case weight to charge weight ratio (M/C) for the weapon. The total case weight (case, nose, fins, and fuze) should not be used in determining the ratio. Rather, it is recommended that only the case weight immediately adjacent to the explosive charge in the radial direction be used.

Initial Conditions in Structural Compartment. In order to calculate internal blast characteristics, it is necessary to specify the initial geometric properties of the structural compartment in which the explosion occurs and of the air that is confined in the compartment. Specifically for this computer program, they are (1) initial ambient pressure and temperature of the confined air (air is treated conventionally as 79% N_2 and 21% O_2 by volume), (2) initial gas volume of the compartment, (3) initial vent area for confined gases (would include opening from projectile entry and additional openings from fragment penetrations), and (4) ambient pressure or backpressure against which venting would occur, i.e., air pressure outside the compartment. If the ambient conditions of items (1) and (4) are the same as those for air at the altitude at which the aircraft is located, only the altitude of the aircraft need be specified. For this case the computer code has the 1959 ARDC standard atmosphere taken from reference (2) as a subroutine for determination of the initial ambient pressure and temperature.

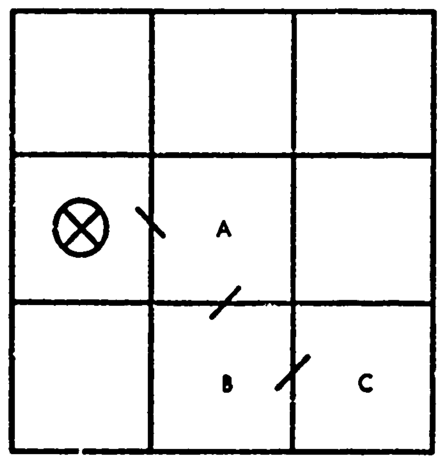
Shock Calculations. To make any shock calculation, the distance from the point of detonation to a desired location in the compartment must be designated. Specifically for this problem, this distance is measured radially from the point of detonation to the point on the structure wall where shock pressure-time information is desired. As input to the code the total number of different distances of interest must be specified, followed by a list of these desired

distances. In this manner the variation of shock loading as a function of location on a particular structural wall can be determined. There are two options in the code that must be specified as input depending on the type of shock and confined-explosion gas calculations desired. For normal code operation where both shock and confined-explosion gas pressure calculations are of interest, option 1 is used with the number and list of distances. However, if shock calculations are not desired, then option 1 is used and the number of distances is set to 0, and the shock calculation section of the program is bypassed. On the other hand, if one wishes to examine only shock calculations, option 2 is used with the number and list of distances, and the confined-explosion gas pressure section of the program is bypassed.

Volume and Vent Area Changes. It is quite possible that damage to an aircraft from an internal projectile explosion will propagate beyond the confines of the initial compartment where detonation occurs. Excessive shock loading or confined-explosion gas pressure may fail a compartment wall allowing the confined gases to propagate to an adjacent compartment. If this pressure remains excessive, additional wall failures may occur with the subsequent spread of the confined gases. As the gases propagate to different compartments and occupy larger volumes, the pressure is reduced. When the confined-explosion gas pressure has decreased to the point where wall failure does not occur, the damage propagation stops. Although a structural response code will eventually be interfaced with this blast loading code to assess the damage propagation to these pressure loads, a skeleton format is provided in this code to allow for an initial examination of the propagation phenomena. As an example, take the box structure represented in Figure 3.1 where the initial explosion occurs in the compartment with the circled X. Through wall failure (sides with cross-lines), the damage may propagate to compartments A, B, and C. It is necessary to specify certain conditions that control the damage propagation such as wall failure criteria and the amount and condition of the air in the adjacent compartments. There are three options available in the code to specify desired characteristics of compartment wall failure.

The table in Figure 3.1 is an example of failure criteria option 3. Interpretation of this input table to the computer program is as follows. (1) If the confined-explosion gas pressure in the initial compartment is above 45 psia 0.15 sec after detonation, the wall fails allowing the gases to mix with 4 ft^3 of air at 14.7 psia and 20°C in compartment A and providing an arbitrary additional vent area of 0.00545 ft^2. (2) If the gas pressure after mixing with air in compartment A is above 20 psia 0.60 sec after detonation, the next wall fails exposing compartment B which has 4 ft^3 of 14.7 psia, 20°C air and an additional arbitrary vent area of 0.00545 ft^2. (3) If the gas pressure after mixing in compartment B is above 19 psia, wall failure occurs involving compartment C, etc. Option 3 offers both pressure and response time control on damage criteria. If at any step the pressure is below the tabulated value at the specified time, propagation stops. For example, if the pressure is below 20 psia at 0.60 sec after detonation, damage does not propagate to compartments B or C.

Damage criteria options 1 and 2 are simplified versions of the above. Option 1 specifies only the pressure failure levels with wall failures occurring instantaneously in time. Option 2 specifies only the time of failure irrespective of pressure level. Both of these options, like option 3, require as input the volume and ambient conditions of the air in the various compartments and any additional vent area



FAILURE PRESSURE (PSIA)	FAILURE TIME (SEC)	ADDITIONAL VOLUME (CU FT)	ADDITIONAL AREA (SQ FT)	AMBIENT PRESSURE (PSIA)	AMBIENT TEMPERATURE (C)
45	.15	4	.00545	14.7	20
20	.60	4	.00545	14.7	20
19	.80	4	0	14.7	20

FIG. 3.1 EXAMPLE OF FAILURE CRITERIA RESULTING IN VOLUME AND VENT AREA CHANGES

TABLE 3.1
LIST OF EXPLOSIVE PROPERTIES
(BASED ON DATA FROM REF. 1)

INDEX NUMBER	EXPLOSIVE NAME	EQUIVALENT WEIGHT f_e	HEAT OF FORMATION (CAL/GM)	WEIGHT FRACTIONS OF COMPONENTS				
				C	H	N	O	AL
1	TNT	1.00	-78.40	0.370	0.022	0.185	0.423	0
2	TNETB	1.13	-307.1	0.186	0.017	0.217	0.580	0
3	EXPLOSIVE D	0.85	-386.3	0.293	0.025	0.227	0.455	0
4	PENTOLITE	1.17	-242.8	0.280	0.024	0.182	0.514	0
5	PICRATOL	0.90	-238.5	0.329	0.024	0.207	0.440	0
6	CYCLOTOL	1.14	22.79	0.225	0.026	0.320	0.429	0
7	COMP B	1.10	4.33	0.252	0.026	0.298	0.424	0
8	RDX/WAX 98/2	1.19	57.00	0.176	0.030	0.371	0.423	0
9	COMP A-3	1.09	24.93	0.225	0.038	0.344	0.393	0
10	TNETB/AL 90/10	1.23	-276.4	0.168	0.014	0.196	0.522	0.100
11	TNETB/AL 78/22	1.18	-239.5	0.146	0.012	0.170	0.452	0.220
12	TNETB/AL 72/28	1.18	-221.1	0.134	0.011	0.157	0.418	0.280
13	TNETB/AL 65/35	1.23	-199.6	0.121	0.010	0.142	0.37[illegible]	0.350
14	TRITONAL	1.07	-62.72	0.296	0.018	0.148	0.338	0.200
15	RDX/AL/WAX 88/10/2	1.30	50.38	0.160	0.027	0.333	0.380	0.100
16	RDX/AL/WAX 78/20/2	1.32	43.76	0.144	0.024	0.295	0.337	0.200
17	RDX/AL/WAX 74/21/5	1.30	29.36	0.163	0.027	0.280	0.320	0.210
18	RDX/AL/WAX 74/22/4	1.30	33.28	0.154	0.026	0.280	0.320	0.220
19	RDX/AL/WAX 62/33/5	1.19	21.42	0.143	0.024	0.235	0.268	0.330
20	TORPEX II	1.24	-3.57	0.216	0.021	0.233	0.350	0.180
21	H-6	1.27	-12.56	0.223	0.025	0.224	0.318	0.210
22	HBX-1	1.21	-22.93	0.249	0.026	0.221	0.334	0.170
23	HBX-3	1.16	-21.83	0.200	0.022	0.171	0.257	0.350
24	TNETB/RDX/AL 39/26/35	1.24	-102.6	0.115	0.013	0.184	0.338	0.350
25	ALUMINUM	0	0	0	0	0	0	1.000
26	WAX	0	-392.0	0.856	0.144	0	0	0
27	RDX	0	66.16	0.162	0.027	0.379	0.432	0
28	PETN	0	-407.1	0.190	0.026	0.177	0.607	0
29	TETRYL	0	16.26	0.293	0.017	0.244	0.446	0

CHAPTER 4

SHOCK WAVE CALCULATIONS

Base Data. The principal thesis of the shock wave calculations in this computer program is that a cased, cylindrical charge of a given type and amount of explosive detonated at any altitude from sea level to at least 50,000 ft can be equated to a free-field 1-lb TNT spherical explosion at sea level. Generally explosion data given in handbooks for TNT do not provide sufficient information to yield the pressure-time history of the shock at a specified distance from the explosion; usually only peak pressures, positive phase durations, and positive impulses are given. One must turn to various hydrodynamic codes to obtain such information in lieu of extensive experimental data. However, such codes are lengthy and expensive to run and do not lend themselves to the objective of this program. It was decided to use results from a current version of the WUNDY hydrocode developed at NOL and described in reference (3), to normalize these results to form a family of pressure-time curves for a large number of distances, and to find the best empirical fit to represent these results.

Figure 4.1 shows four representative curves developed by WUNDY that demonstrate the incident pressure-time behavior of a free-field shock wave as a function of distance, R. From some 25 curves of this type that exist outside the explosion gas contact surface, it was found that the family could be represented quite well by the equation.

$$\pi = \Delta P/\Delta P_i = (1 - \tau)\, e^{-\tau\left(1 + \frac{\sigma}{A+\tau}\right)} \qquad (4.1)$$

where

$$\tau = (t - t_a)/t_d$$

$$\sigma = (228/R) - 0.95$$

$$A = 0.5$$

and ΔP_i = peak incident shock overpressure
ΔP = instantaneous overpressure
t = time measured from detonation
t_a = arrival time of shock measured from detonation
t_d = positive phase duration of incident shock pulse
R = distance from detonation (cm)

From the above equations, it is seen that peak incident pressure, arrival time, and positive phase duration for a given distance are the only parameters required for development of the shock pressure-time curve. Values of peak incident overpressure and arrival time are readily available from WUNDY code results and have been tabulated in the computer program for 108 distances ranging from the charge surface to 2.342×10^6 cm (based on 1-lb bare TNT sphere). Positive phase durations for distances outside the contact surface are also obtained from WUNDY. However, inside about 70 cm, the positive phase duration of the shock wave is not completed before interaction with the contact surface occurs. Although WUNDY follows the contact surface boundary, the available runs do not yield usable results inside the contact surface. Therefore, experimental data from references (4) and (5) were used to derive approximate positive phase durations inside the contact surface. The computer code assumes that equation (4.1) continues to hold inside the contact surface. Arrival time of the contact surface is programmed into the code. When shock information is desired at a point inside the contact surface, the user is alerted to the fact that the pressure-time history is an approximation by a diagnostic or warning statement that appears in the code output--"CAUTION--CONTACT SURFACE HAS ARRIVED. DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL =".

As indicated previously, parameter values are tabulated in the computer code for 108 distances. An interpolation method was needed to accommodate any given distance. Plots of peak pressure, shock arrival time, positive phase duration, and contact surface arrival time as functions of distance on log-log scales demonstrated a nearly linear slope over relatively small intervals. Therefore, linear interpolation between the log values of the parameters and the log values of distance is coded into the program as an accurate interpolation method.

Scaling Equations. To relate a spherical TNT explosion at altitude to a 1-lb spherical TNT explosion at sea level, conventional Sachs scaling was used in the computer program. (Sachs scaling method can be found in many references on airblast from explosions, such as reference (6).) The scaling relations, as they are used in this computer code, are given as

$$R_s = R_a (W_s/W_a)^{1/3} (P_a/P_s)^{1/3} \tag{4.2}$$

$$\Delta P_a = \Delta P_s (P_a/P_s) \tag{4.3}$$

$$t_a = t_s (W_a/W_s)^{1/3} (P_s/P_a)^{1/3} (T_s/T_a)^{1/2} \tag{4.4}$$

$$I_a = I_s (W_a/W_s)^{1/3} (P_a/P_s)^{2/3} (T_s/T_a)^{1/2} \tag{4.5}$$

where

- R = distance
- W = charge weight
- ΔP = overpressure
- P = ambient pressure
- t = time
- T = ambient temperature
- I = impulse
- s = subscript denoting 1-lb TNT sphere at sea level
- a = subscript denoting TNT sphere at altitude

Following the order of these equations, for a given distance, R_a, from a spherical TNT charge, W_a, at altitude pressure, P_a, and temperature, T_a; a scaled distance, R_s, from a 1-lb TNT spherical charge (W_s=1) at sea level pressure and temperature, P_s and T_s, is determined. The code then calculates a pressure-time curve for the scaled distance and 1-lb TNT charge at sea level from equation (4.1) and numerically integrates this curve to determine the incident impulse. With values P_s, t_s, and I_s, equations (4.3)--(4.5) define the values of these parameters at the desired altitude. More details of this method will be presented in subsequent sections.

Equivalent Weight. In the previous section on scaling, all charges were TNT spheres. Since typical projectile charges are cased, cylindrical, non-TNT explosives, methods for equating the blast effects of a real projectile to those of an idealized TNT sphere were required. Virtually all studies directed at establishing equivalent weights have been conducted at sea level conditions. The assumption was made for this program that the relative performance of explosives is essentially the same at sea level as at altitude so that equivalent weights do not vary with altitude. The equivalent weight relating various explosive compositions in bare spherical charge form to airblast performance is defined in this report as the energy equivalent weight, f_e, and is given as an explosive property in Table 3.1. Factors relating cylindrical to spherical charges and cased cylindrical to bare cylindrical charges have been shown experimentally to depend on the peak incident overpressure level in a gross sense. Therefore, before evaluating these factors, an estimate of the peak incident overpressure for a spherical explosion scaled to sea level is made based on the energy equivalent weight alone.

First, methods were developed to determine the cylindrical charge equivalent weight. A compilation of data for bare Comp B cylindrical charges was taken from reference (7) for L/D ratios between 2 and 10. It was found that the data formed the three curves shown in Figure 4.2. The 90° curve gives peak incident overpressures measured along a line perpendicular to the longitudinal axis of the cylindrical charges; the 45° curve gives overpressures along a line inclined 45° from the longitudinal axis; and the 0° curve gives overpressures along the extension of the longitudinal axis. The orientation of the projectile with respect to the aircraft compartment structure would vary considerably depending on the mode of attack. Since the design of aircraft to withstand internal blast is of utmost concern for this program, a conservative assumption is to use the curves yielding the highest pressure. In Figure 4.2 this is the 90° curve up to a scaled distance of about 8 and then the 45° curve for scaled distances greater than 8, or the resultant composite cylindrical charge curve shown in Figure 4.3. (If one is interested in weapon selection for damaging aircraft, he would chose the composite curve of 45° and 0° in Figure 4.2.)

From the same DRI study in reference (7), bare spherical charges of the same explosive Comp B were detonated yielding the spherical charge curve in Figure 4.3. Chosing a particular pressure level, one can determine the cylindrical charge equivalent weight (f_s = weight of sphere/weight of cylinder) for equal distances. In this manner the low-pressure curve shown in Figure 4.4(a) was developed. Empirical relations that represent this curve

$$0 \leq \Delta P_i \leq 20 \quad ; \quad f_s = 1.45 \tag{4.6}$$

$$20 \leq \Delta P_i \quad ; \quad f_s = 0.613 \, (\Delta P_i)^{0.287} \tag{4.7}$$

have been programmed into the computer code. It is assumed in the program that all explosives follow the behavior of this experimental data for Comp B. Lack of complete sets of data for other explosive compounds makes this assumption necessary.

In Figures 4.2, 4.3, and 4.4, the experimental data do not extend to overpressures above 100 psi. To limit shock calculations to this experimentally verified range is too restrictive for a realistic problem where the projectile will generally be relatively close to a structure wall where incident overpressures above 100 psi will surely exist. It is improper to assume that the cylindrical charge equivalent weight will continue to increase indefinitely with pressure as given by equation (4.7). As the distance from the cylindrical charge decreases, at some point the charge will begin to appear as an infinitely-long charge or a line charge, and the equivalent weight will begin to decrease. Since no experimental data are available to provide guidance for determining equivalent weights for pressures above 100 psi, the following method is assumed. From theoretical work on line charges developed by Kirkwood and Brinkley in reference (8), the high-pressure curve shown in Figure 4.4(b) was determined. Note that the ordinate is not equivalent weight as in Figure 4.4(a), but rather a term defined for this report as comparative weight index. From the L/D ratio of the charge, this index can be converted to the equivalent weight, f_s. If one makes this conversion over the entire curve, a family of curves is generated and shown as the various L/D curves in Figure 4.5. The transition from a line charge to a cylindrical

charge of finite length is made by extending the low-pressure curve in Figure 4.4(a), or equation (4.7), until it intersects this family. Thus Figure 4.5 represents the composite example of the method used by the computer to calculate the cylindrical charge equivalent weight. Although the trend of the assumed method agrees with the expected physical behavior of cylindrical charges, any shock calculations based on this method must be viewed as approximations. Because of the uncertainty associated with this approach and the lack of experimental verification of pressure data above 100 psi for cylindrical charges in general, a diagnostic or warning statement in the computer output appears--"CHARGE SHAPE CORRECTION IS CRUDE. PSI EXCEEDS RANGE OF EXPERIMENTAL DATA".

Secondly, a method to determine the effects on airblast shock of a metal casing surrounding a cylindrical charge was required, i.e., a casing equivalent weight, f_c, to relate cased and bare cylindrical charges. As found in reference (9), a number of methods have been proposed and are given in Figure 4.6. These curves alone give no insight to the best approximation of the casing effects. Assorted case effects experimental data taken from references (10)—(13) have been plotted in Figure 4.6. Whereas it appears that the equation

$$f_c = 0.20 + 0.80/(1 + M/C); \quad M/C = \text{case weight/charge weight}$$

best fits the experimental data, it is noted that it slightly underestimates the effects of the case for much of the data. Consistent with previous assumptions for the cylindrical charge equivalent weight, the most conservative method was sought, i.e., the method that yields the greatest pressures. This was accomplished by combining the upper two curves into one as plotted in Figure 4.7 with a replot of the experimental data points. It is noted that only one data point lies above this curve. Therefore, the casing equivalent weight used in the computer program is expressed as

$$0 \leq M/C \leq 0.53$$

$$f_c = \frac{1 + (M/C)(1-M')}{1 + M/C} = 1 - (M/C)^2/(1 + M/C) \qquad (4.8)$$

$(M' = M/C$ for values of M/C less than $1)$

$0.53 \leq M/C$

$$f_c = 0.47 + 0.53/(1 + M/C) \qquad (4.9)$$

(Again, if one were interested primarily in weapon selection rather than aircraft design, the lower curves of Figure 4.6 would be more suitable.) It should be pointed out that the experimental data used for casing effects were based on measured incident overpressures less than 100 psi. Therefore, a warning statement appears in the computer output to alert the user to the approximate nature of the data for overpressures above 100 psi--"CASE WEIGHT CORRECTION IS CRUDE. PSI EXCEEDS RANGE OF EXPERIMENTAL DATA".

From the above discussions, a cylindrical, cased, non-TNT explosive charge can be related to a bare spherical TNT charge by the expression

$$W_{TNT} = W \times f_e \times f_s \times f_c \qquad (4.10)$$

where

W_{TNT} = weight of equivalent bare spherical TNT charge

W = weight of cased charge

f_e = energy equivalent weight from Table 3.1

f_s = cylindrical charge equivalent weight from Figure 4.4 or 4.5

f_c = casing equivalent weight from equations (4.8) and (4.9)

Free-Field Incident Pressure-Time and Impulse. Using equation (4.10) and the scaling equation (4.2), the computer can scale a high explosive projectile explosion at altitude to a free-field, bare, spherical 1-lb TNT explosion at sea level. For a specific scaled distance, the computer selects appropriate free-field explosion data required for the pressure-time equation (4.1). It then calculates incident free-field overpressures that correspond to equal time steps during the positive phase duration of the shock wave. The number of equal time steps, k, can be varied from 10 to 40; however, the number should be as large as conveniently possible because these time steps control the numerical integration procedure that calculates the positive impulse as seen by the following equation

$$I = \sum_{i=0}^{i=k} [\Delta P(i) + \Delta P(i-1)] \Delta t/2$$

$$\Delta t = t_d/k$$

where

I = incident impulse

ΔP = incident overpressure

i = step index

Δt = time interval

t_d = positive duration

k = number of time steps

For the convenience of the user, time is measured both from the instant of detonation and from the instant of shock arrival at the desired distance from the explosion. The tabulated incident pressure-time information and the incident impulse are then scaled to the actual conditions at altitude using the scaling equations (4.3)--(4.5).

Normally Reflected Pressure-Time and Impulse. As stated in the general program description, accurate analysis of shock reflection in a structure of an arbitrary configuration is presently beyond the scope of this code. Normally reflected pressure-time information and normally reflected impulse have been chosen as loading indices for studying structural response to shock loading. For the small structural compartments in aircraft, shock loading from the relatively small explosive charges in anti-aircraft projectiles would be completed before any appreciable plastic response of the structure has occurred. Therefore, the shock basically can be treated as an impulsive load on an aircraft compartment structure, and it is believed that the normally reflected explosion data developed be the computer code will be sufficient to index the response of the structure to shock loads. While this assumption is sufficient, in all probability, when applied to small aircraft compartment structures, it might prove restrictive and limiting for code application to response problems

relating to large structures such as ship compartments or building rooms.

Methods for predicting the peak normally reflected overpressure have been developed and verified by experimental data over a wide range of pressure. The method used in this computer program is based on the reflection factor curve developed by Brode in reference (14) and shown in Figure 4.8 as the solid curve. With sufficient accuracy this curve is approximated by the combination of dashed curves shown in this figure. In the computer program the following equations are used to calculate reflection factors for the peak normally reflected overpressure at sea level conditions.

$0 \leq \Delta P_i \leq 200$ psi

$$f_R = 2\left[\frac{(7)(14.7) + 4\ \Delta P_i}{(7)(14.7) + \Delta P_i}\right] \tag{4.11}$$

$200 < \Delta P_i \leq 10{,}000$ psi

$$f_R = -3.18 + 3.97 \log_{10} (\Delta P_i) \tag{4.12}$$

$10{,}000 < \Delta P_i$

$$f_R = 13 \tag{4.13}$$

where ΔP_i = peak incident shock overpressure.

The major problem now is how to relate this normal reflection factor derived for the peak reflected overpressure to the entire reflected pressure-time history and reflected impulse. Whereas hydrocodes exist that will follow the normally reflected shock phenomena in time, they do not lend themselves economically for use with this program. For the lack of a better method at this time, it is assumed that an adequate approximation to the reflected pressure-time history is found by multiplying the pressure level of the previously calculated incident pressure-time history by the reflection factor, f_R, derived for the peak reflected pressure. Thus the computer program multiplies the incident pressures as they are determined for the 1-lb TNT sphere at sea level by the appropriate

reflection factor, f_R, from equations (4.11)--(4.13) using the peak incident peak overpressure. It then scales these results to altitude conditions in the same manner as it scales the incident pressures. Likewise, the incident impulse is multiplied by the same reflection factor to obtain the normally reflected impulse.

If one wishes to evaluate a reflection condition other than normal, it is possible to modify the incident pressure-time curve with a reflection factor for an angle of incidence other than normal (90°). Such reflection factors can be found in Figure 4-6 of reference (15) and in Figure 3.71b of reference (16). With the uncertainties involved in this approach to reflected pressure-time histories, caution should be exercised in using the referenced factors for other angles of incidence with this method except to serve as an index or for scoping calculations.

Comparisons with Experimental Data. Since normally reflected pressure-time and impulse information are assumed to be the important shock characteristics in terms of aircraft compartment structure damage, it is most important that the code predicts normally reflected shock phenomena accurately. Unfortunately, documentation of experimental programs studying reflected shock data relatively close to the explosion has been difficult to find. The best available set of data was found in the BRL study reported in reference (5). This report presented experimental curves for peak reflected pressure and reflected impulse based on old and new tests with bare, spherical pentolite charges.

These curves are shown in Figures 4.9 and 4.10 along with calculated results from the computer program depicted by the circles. Peak reflected pressure predictions agree remarkably well with the experimental curve in Figure 4.9. Reflected impulses agree well with the experimental curve in Figure 4.10, but the relative variation is not as good as for peak reflected pressure. In all fairness to the computer program, a close study of the spread of experimental data from which the impulse curve was drawn (Figure 8 of reference (5)) reveals experimental variation as large as that observed from the code prediction-experimental curve comparison. It is important to

note here that these experimental data extend to the very high pressure range and that the reflected impulse for some of the tests include effects inside the contact surface--all questions of uncertainty in the formulation of the code. Therefore, it must be concluded that the computer code yields predictions that agree remarkably well with this set of experimental data, which certainly provides confidence to the use of the computer program for shock calculations.

Additional confidence is gained from a comparison of a reflected pressure-time trace from one of the BRL experiments with a code predicted reflected pressure-time history. Figure 6 of reference (5) gives an enlargement of a reflected pressure-time trace from a 1/8-lb pentolite test at a scaled distance of 2.5 $ft/lb^{1/3}$. This curve, which is free of extraneous noise and oscillations, is shown in Figure 4.11 as the solid curve. Shown as the dashed curve is the predicted reflected pressure-time results from the computer code. Agreement has to be classified as excellent in light of all the simplifying assumptions used in the code for shock calculations.

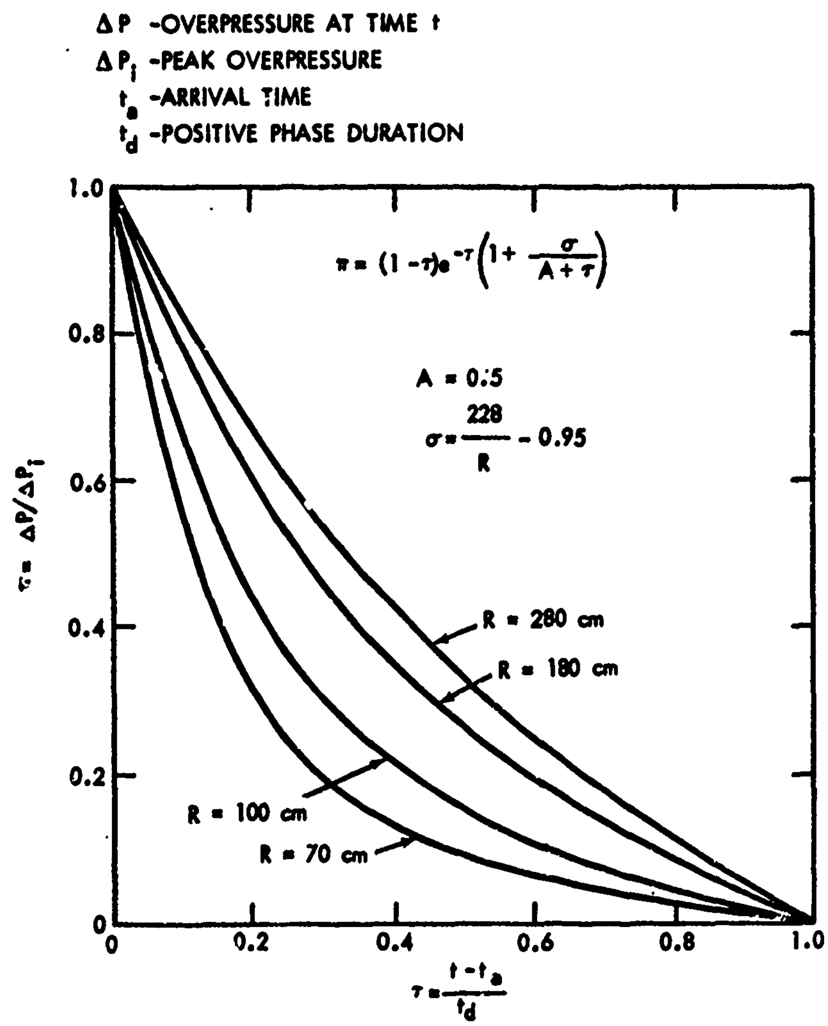


FIG. 4.1 SHOCK PRESSURE-TIME WAVE FORMS

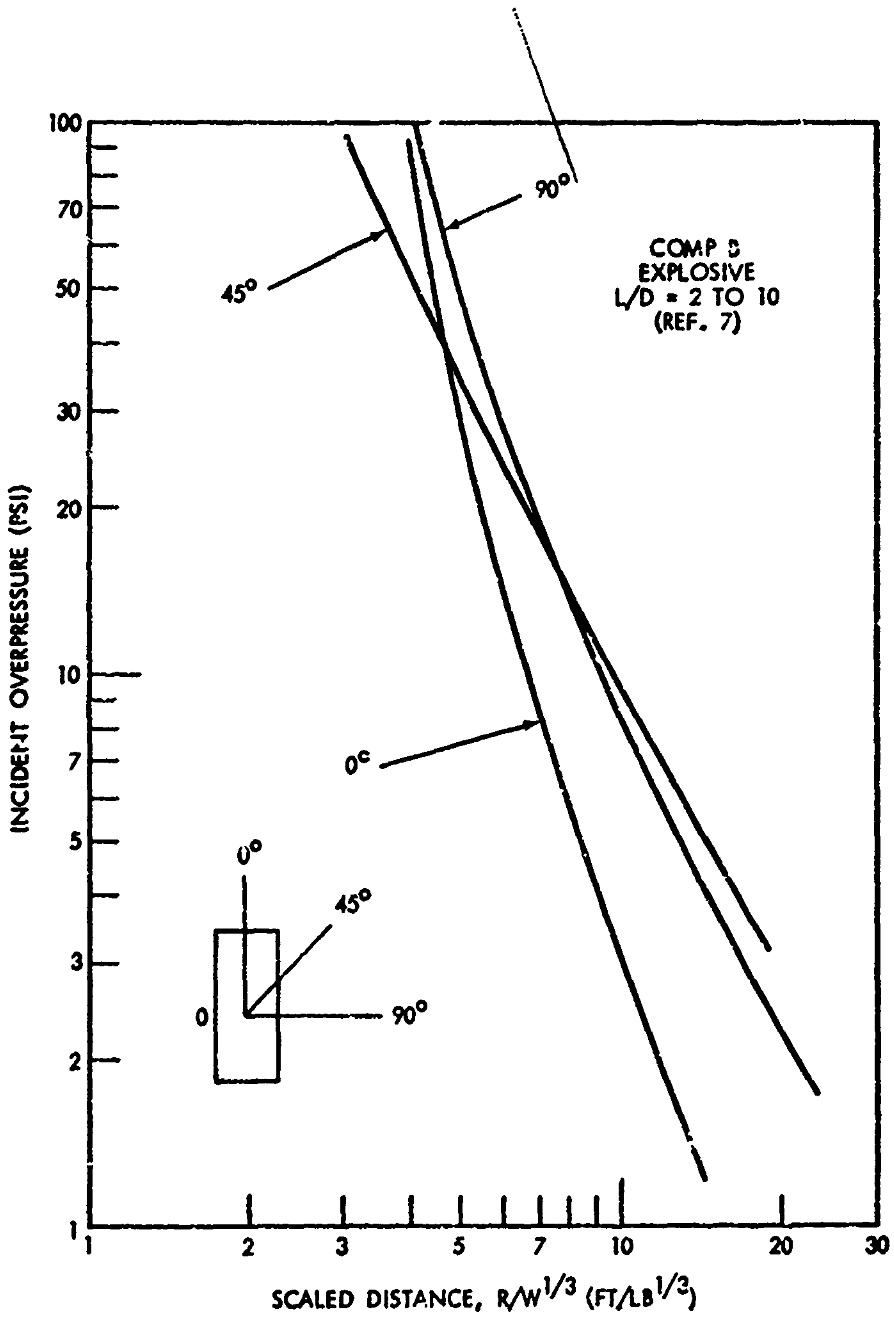


FIG. 4.2 PRESSURE-DISTANCE CURVES FOR VARIOUS ANGLES FROM AXIS OF CYLINDRICAL CHARGE

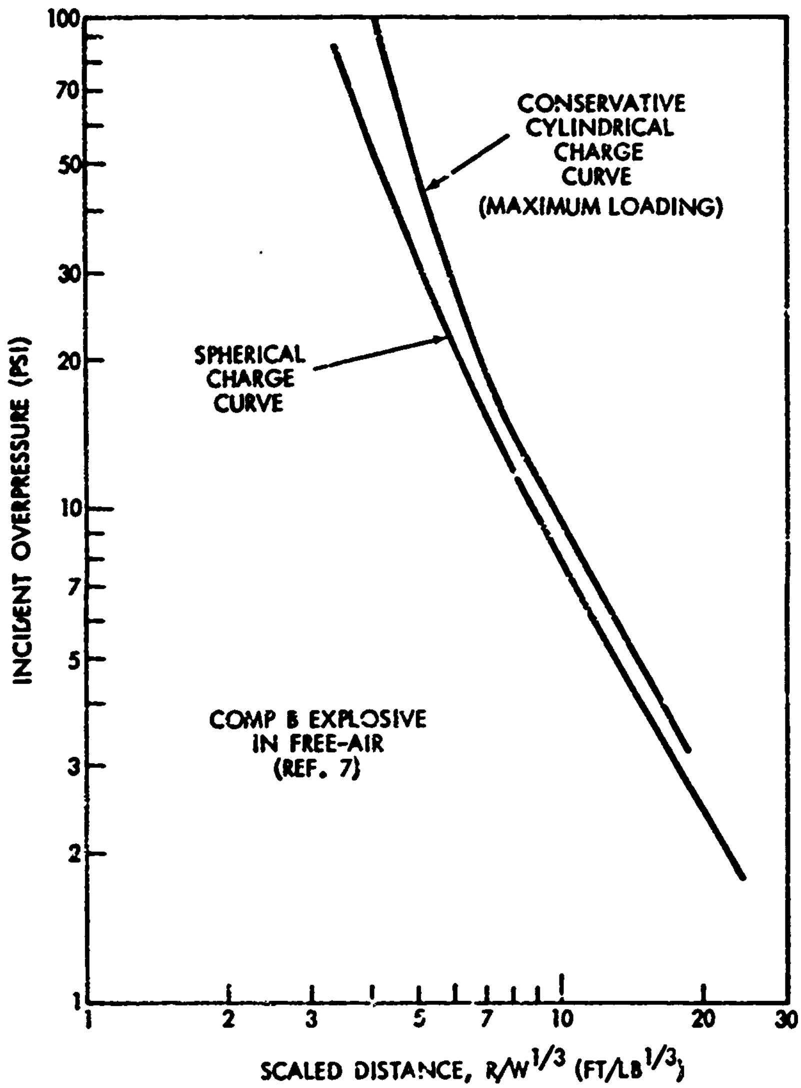
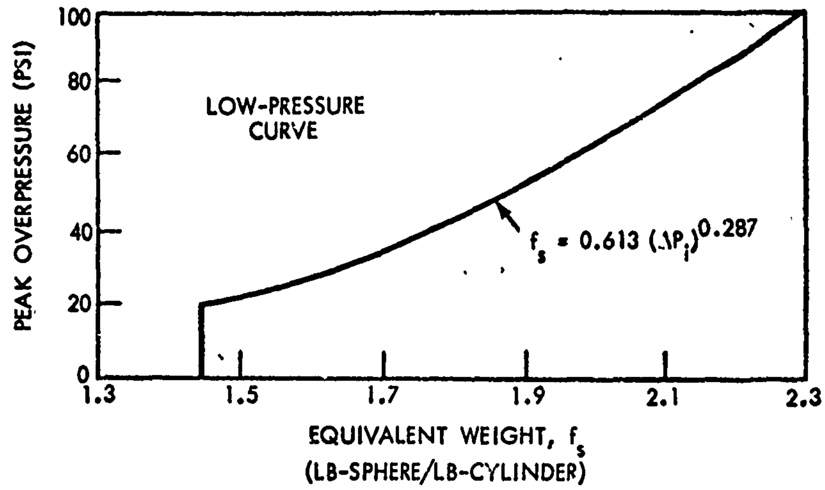


FIG. 4.3 COMPARISON OF PRESSURE-DISTANCE CURVES FOR CONSERVATIVE CYLINDRICAL AND SPHERICAL CHARGES

(a)



(b)

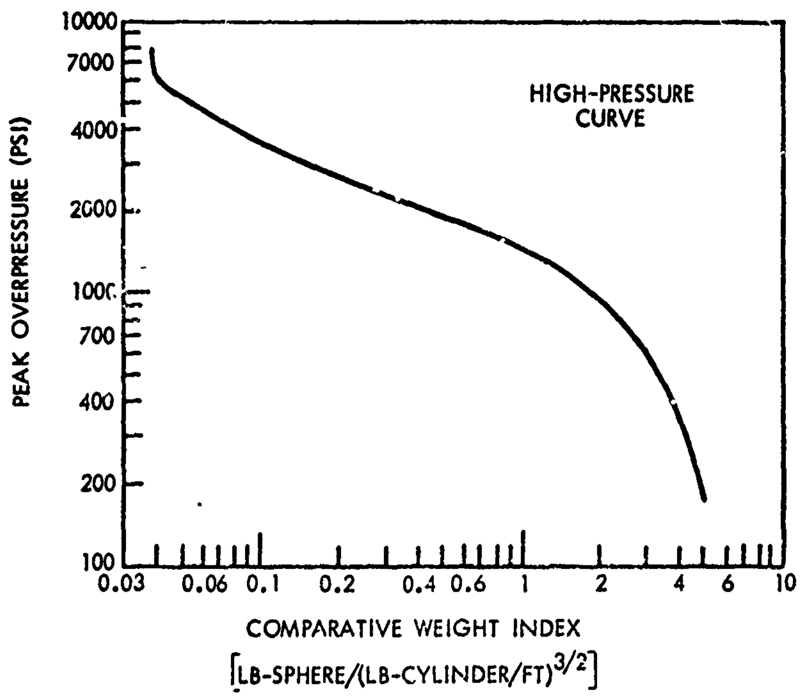


FIG. 4.4 CYLINDRICAL CHARGE EQUIVALENT WEIGHT

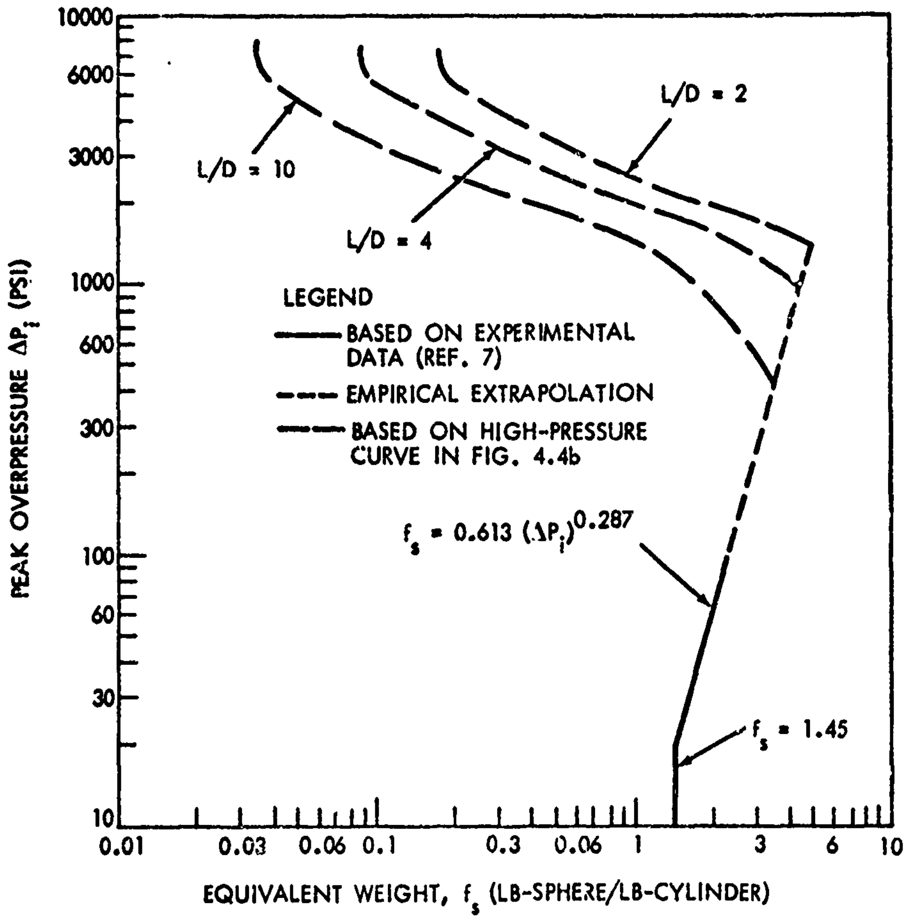


FIG. 4.5 COMPOSITE EXAMPLE OF CYLINDRICAL CHARGE EQUIVALENT WEIGHT

CURVES FROM REF. 9
DATA POINTS FROM REFS. 10-13

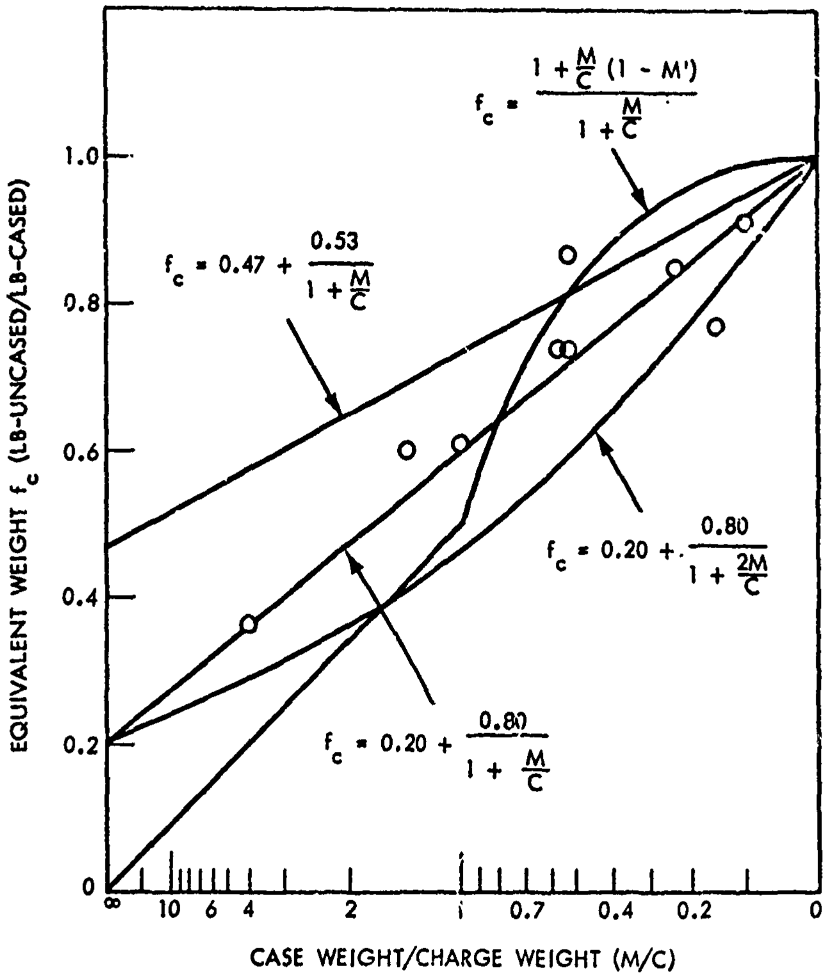


FIG. 4.6 VARIOUS METHODS FOR PREDICTING CASE EFFECTS

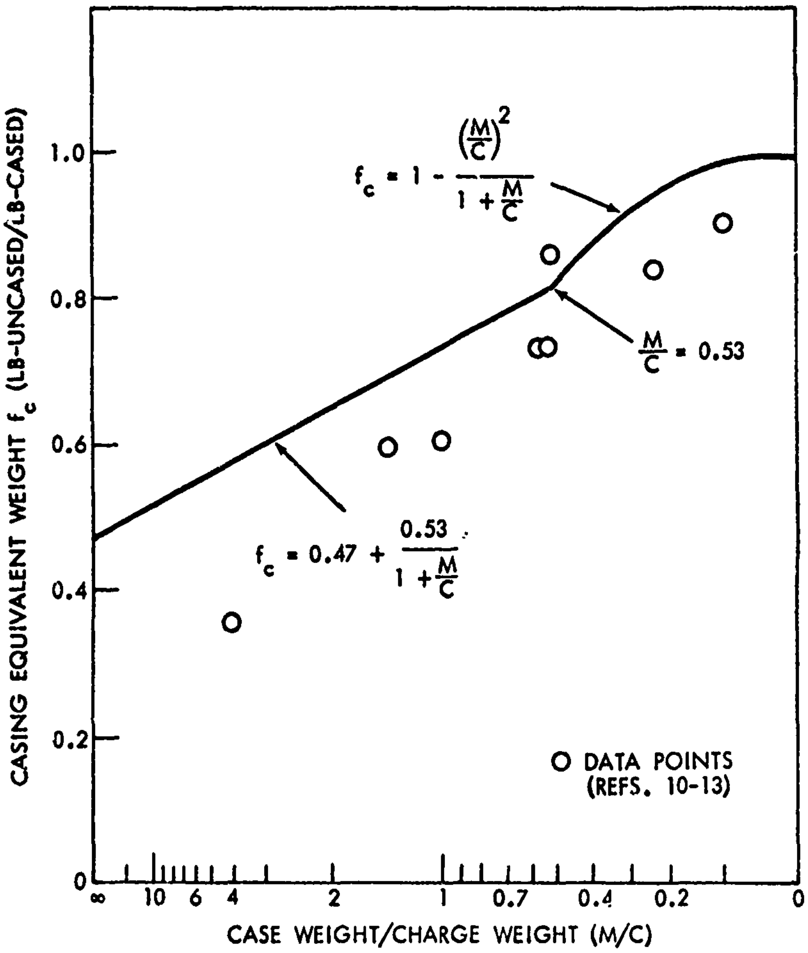


FIG. 4.7 CASING EQUIVALENT WEIGHT (MAXIMUM LOADING)

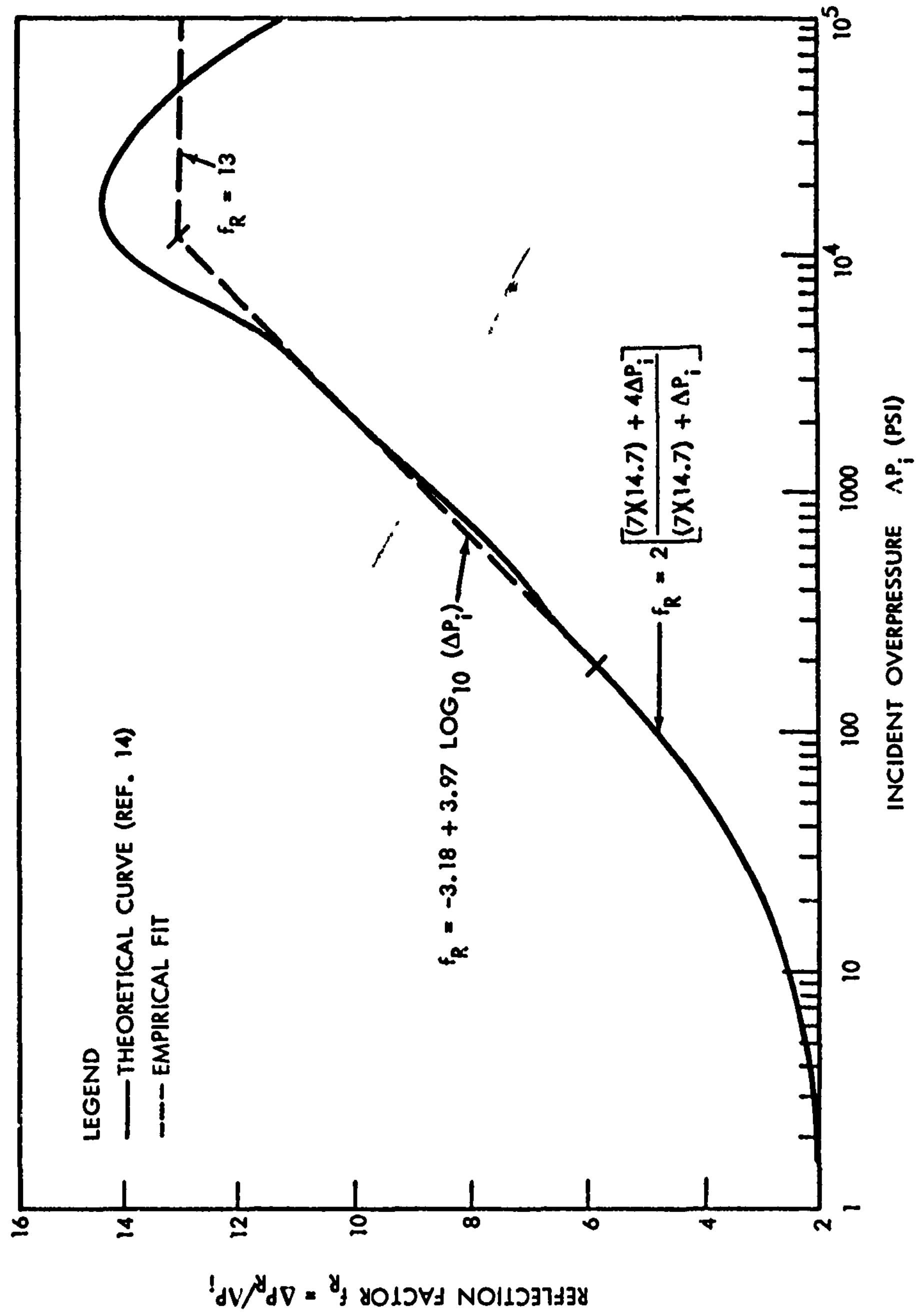


FIG. 4.8 NORMAL REFLECTION FACTORS

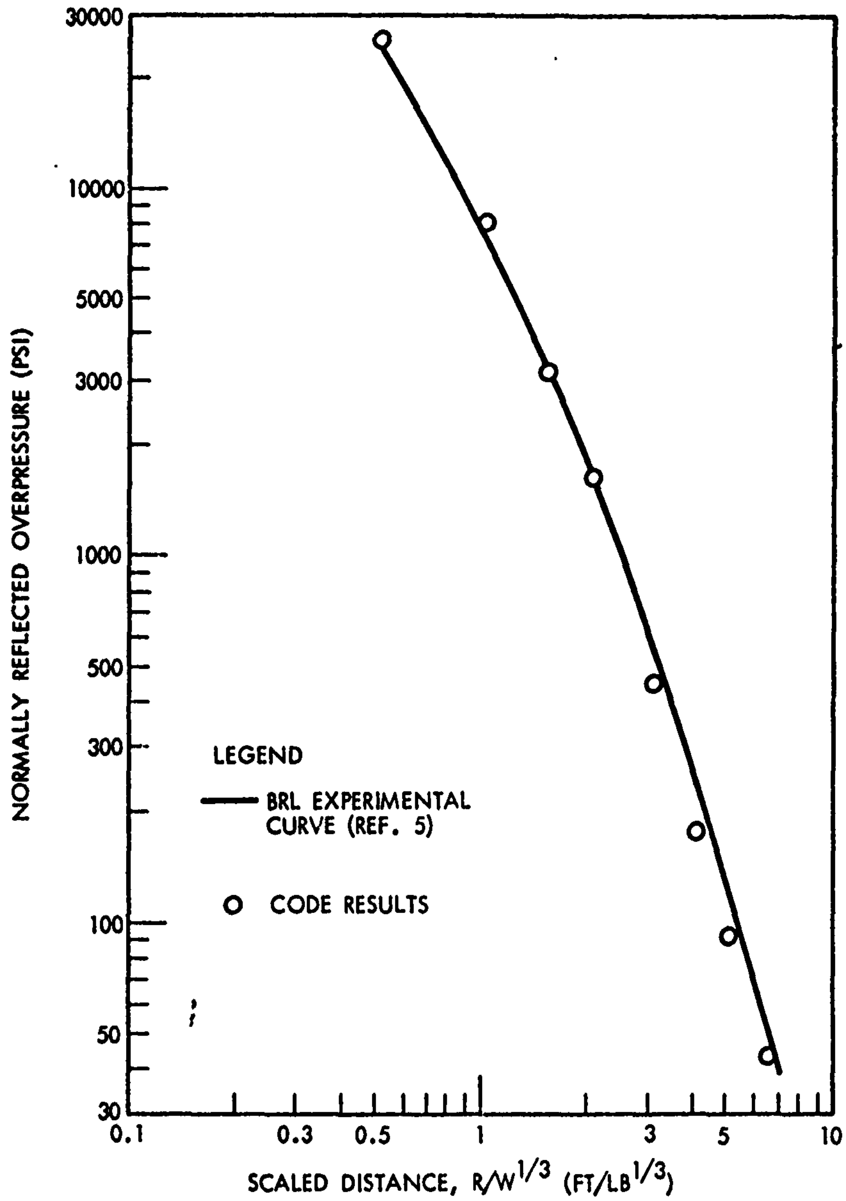


FIG. 4.9 REFLECTED PRESSURE-DISTANCE CURVE FOR PENTOLITE IN FREE-AIR AT SEA LEVEL

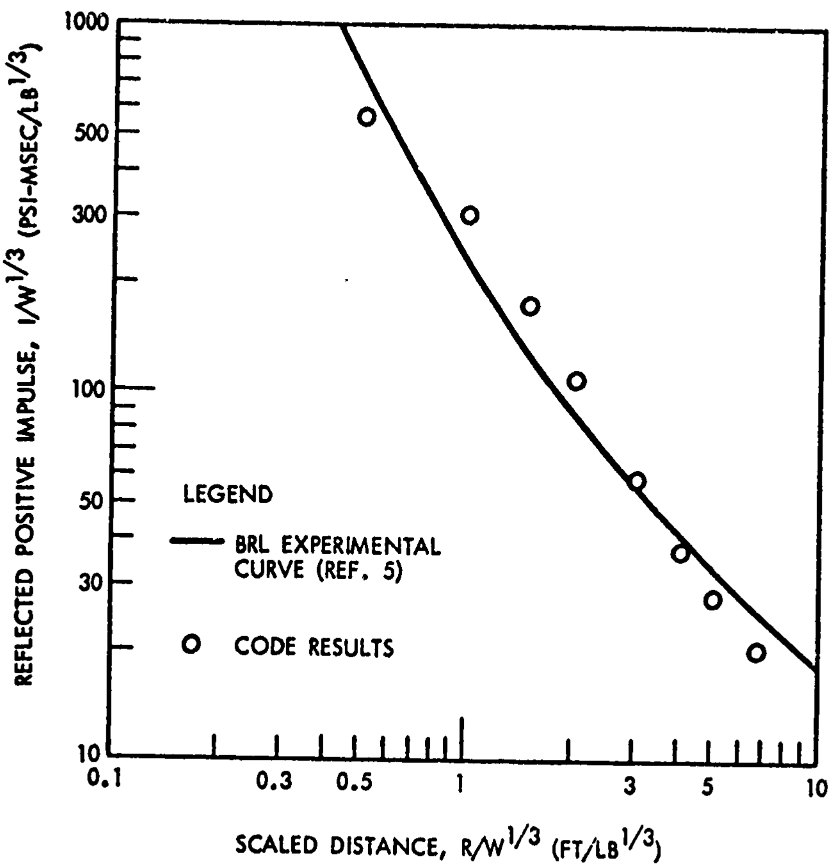


FIG. 4.10 REFLECTED POSITIVE IMPULSE-DISTANCE CURVE FOR PENTOLITE IN FREE-AIR AT SEA LEVEL

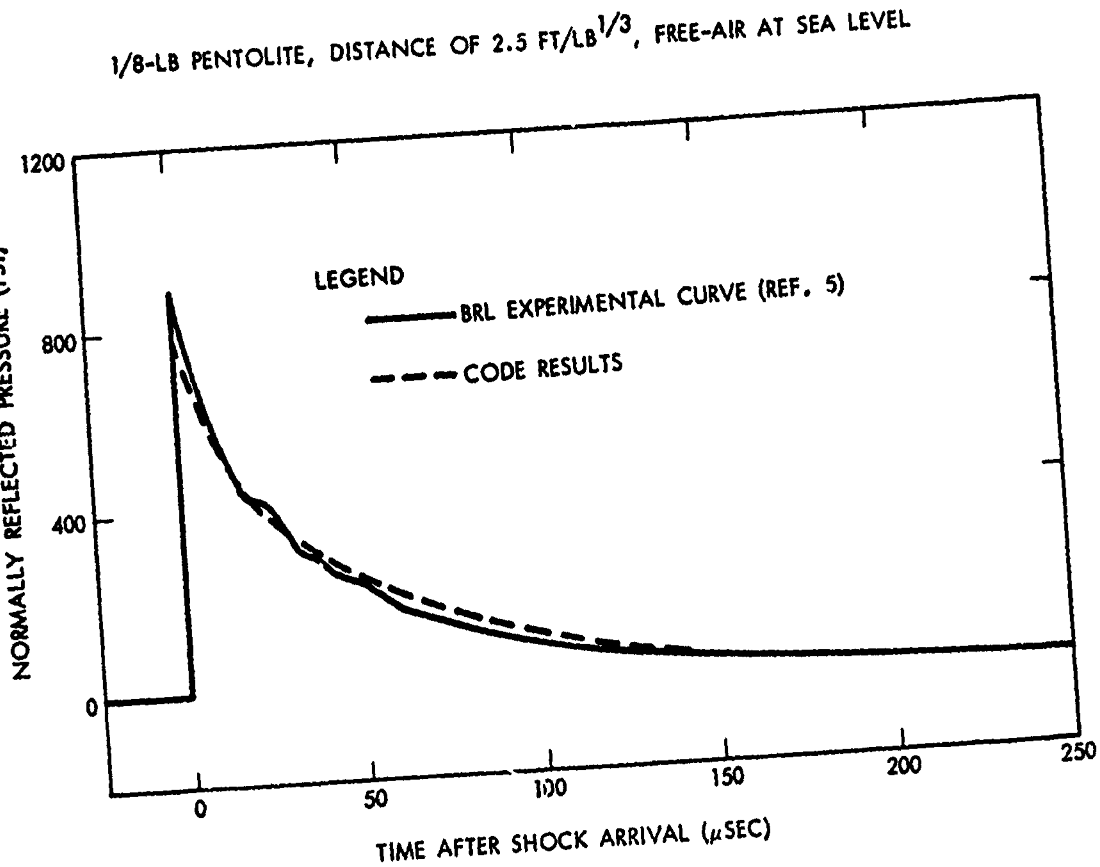


FIG. 4.11 COMPARISON OF CODE AND EXPERIMENTAL SHOCK PRESSURE-TIME HISTORIES

CHAPTER 5

CONFINED-EXPLOSION GAS PRESSURE CALCULATIONS

Phenomena Description. The development of the quasi-static pressure that exists in a closed structure after an explosion is presented in detail in references (17) and (18). It is briefly discussed here. After the multitude of shock reflections from an explosion in a completely closed structure have dissipated, there exists a significant overpressure in the structure. A tremendous amount of heat is released from the chemical decomposition of the explosive charge and from subsequent reactions with oxygen in the surrounding air in the structure. Mixing of the extremely hot explosion gas products with the initial gas in the structure results in an elevated equilibrium temperature of the gas mixture. Since the volume of the structure remains essentially constant during the explosion, the elevated temperature must be accompanied by an increase in the equilibrium pressure of the gas mixture. The process can be viewed to be similar to a combustion test in a bomb calorimeter. The pressure will slowly decay with time due to heat losses to the structure walls; however, in comparison with the highly transient nature of the shock phenomena, this pressure can be truly defined as quasi-static.

Historically in the literature, this quasi-static pressure has been known by different names such as static pressure, steady overpressure, internal blast pressure, post-detonation pressure, and chamber pressure. It is assumed that the reason that no single name has evolved is because there has been misinterpretation of existing names or it has been felt that existing terms do not adequately describe the phenomena. Therefore to add to the growing list of names and hopefully to clarify, this quasi-static pressure created by mixing the hot explosion gas products with the initial gas in the closed structure is simply defined in this report as the confined-explosion gas pressure.

Existing Methods of Calculation. Currently there are two commonly used methods for estimating the magnitude of the confined-explosion gas pressure; that proposed by Filler in references (17) and (18) and that proposed by Weibull in reference (19). Filler proposed that the confined-explosion gas pressure can be calculated from an expression equivalent to

$$\Delta P_g = (4hW)/V_o$$

where ΔP_g = confined-explosion gas pressure (overpressure), psi

h = heat of combustion of explosive, cal/gm

W = weight of explosive, lb

V_o = volume of closed structure, ft^3

This method assumes that there is sufficient oxygen in the initial air in the closed structure to ensure that an oxygen-deficient explosive will achieve complete combustion. It also assumes that the specific heat of the gas mixture remains constant. This approach was verified for small quantities of different explosives detonated in a large air-filled chamber resulting in modest confined-explosion gas pressures up to about 30 psi. Realizing the deficiency in the use of the heat of combustion in a possibly oxygen-poor atmosphere, Filler conducted experiments in an inert atmosphere and found results that indicated the heat of detonation yielded accurate agreement for this case, as expected. Unfortunately these studies did not determine analytical relations that describe the phenomena in the transition region between the heat of combustion and heat of detonation. Neither did they extend to the high-pressure region where the effects of variations in gas specific heats could be observed readily.

Weibull proposed that the confined-explosion gas pressure for a TNT charge can be calculated from the expression

$$\Delta P_g = 2410\ (W/V_o)^{0.72}$$

This method was an empirical fit to experimentally measured pressures from TNT explosions. Unlike Filler's method, there are no means of relating this equation to explosives other than TNT. However, Weibull's experimental data extends into the high-pressure range (near 1000 psi) where obviously the specific heats of the gas mixture components are changing and the transition between heat of combustion and heat of

detonation can be observed. Unfortunately, this study was limited to an empirical approach without fully exploring the underlying phenomena.

Need for Improved Method. Figure 5.1 gives the prediction curves proposed by Filler's method and Weibull's method. Weibull's extensive TNT data are also plotted for direct comparison. The deficiencies of these two methods become obvious from the comparison. Because complete combustion and a constant specific heat of the gas mixture were assumed, Filler's method becomes decreasingly accurate as the pressure level increases. Even if the heat of detonation is used with Filler's method (the lowest curve in Figure 5.1), the deficiencies in handling the transition region are easily recognized. Weibull's curve approximates the TNT data better than Filler's method over the range of data, but it is all too clear that important physical phenomena are being glossed over in the empirical treatment of the problem that makes it impossible to extend this method to any explosive other than TNT.

Since the confined-explosion gas pressure is believed to be the most important loading parameter in the aircraft internal blast problem, it was imperative that an improved method for calculating the confined-explosion gas pressure be developed. The following sections describe the technique contained in the computer program for predicting the confined-explosion gas pressure and comparing code results with available experimental data.

Description of Improved Method. The improved method assumes an explosion in a closed structure of volume, V_o, filled with air at some ambient pressure, P_a, and temperature, T_a. The explosive is limited to a hydrocarbon form of the elements C, H, O, and N with aluminum being the only possible metallic additive. Since most explosive compounds are oxygen-deficient, it is assumed that the reaction can consume all of the oxygen in the air in the closed structure, if needed. This basically is assuming optimum mixing and reaction. The code calculates the number of moles of air initially in the closed structure volume from the perfect gas law. One mole of air is assumed

to be composed of 0.21 mole O_2 + 0.79 mole N_2. From the C, H, O, N, AL composition of the explosive charge given as weight fractions in Table 3.1, the code calculates the number of moles of each of these elements.

The chemical reaction of the explosion and mixing with the air in the closed structure creates the combustion products H_2O, AL_2O_3, CO, CO_2, O_2, and N_2. A priority in the reaction is assumed as follows; (1) the hydrogen in the explosive reacts with oxygen such that all hydrogen appears as H_2O, (2) the aluminum has next priority on the oxygen, such that all the aluminum appears as the solid AL_2O_3, (3) if there is an overabundance of oxygen in the explosive and structure air, complete combustion occurs such that all carbon appears as CO_2 and the remaining oxygen not needed in any of the reactions appears as O_2, (4) if there is insufficient oxygen in the system after the H_2O and AL_2O_3 reactions, then CO and CO_2 are produced in quantities given by the following equations

$$n(C) + m(O) \rightarrow a(CO) + b(CO_2)$$

$$\begin{matrix} a + b = n \\ a + 2b = m \end{matrix} \quad \text{or} \quad \begin{matrix} a = 2n - m \\ b = m - n \end{matrix}$$

where

a = number of moles of CO produced

b = number of moles of CO_2 produced

n = number of moles of C

m = number of remaining moles of O

and no O_2 exists in the final gas mixture, (5) the nitrogen does not participate in the reaction and appears as N_2 in the final gas mixture. From the above calculations the number of moles of component gases (H_2O, CO, CO_2, O_2, N_2) that make up the final gas mixture in the closed structure are known.

The formation of H_2O, AL_2O_3, CO, and CO_2 in this combustion-type process releases a large amount of heat energy. Respective standard heats of formation are multiplied by the moles of individual gas components, and the sum of these quantities is defined for use in this report as the heat of reaction. The heats of formation for the gas products are negative by standard thermodynamic terminology, i.e., if energy is released to the surrounding atmosphere, the heat of formation

is negative. Thus the heat of reaction is likewise negative. However, for convenience in this report, it is desirable to express the total amount of energy, Q, released by the explosion as a positive quantity. The heats of formation of the gas products and the heat of reaction are treated as positive quantities in the computer program. To account for the heat of formation of the explosive compound in determining the total energy, Q, it is necessary to add the heat of formation of the explosive compound given in Table 3.1 to the heat of reaction. (Signs of values in Table 3.1 conform to standard thermodynamic terminology.)

As a computational model only, the gas components of the final gas mixture in the closed structure are assumed to exist at the initial ambient pressure, P_a, and temperature, T_a, of the air in the initial volume, V_o. The energy, Q, is then added to the gas mixture, but it is added in 100°F steps in temperature.

It is well known that the addition of heat to a gas in a constant volume system follows the perfect gas relation

$$\Delta Q = n\, C_v\, \Delta T \tag{5.1}$$

where ΔQ = heat added

n = moles of gas

C_v = specific heat of gas at constant volume

ΔT = change in temperature

One of the weaknesses of previous methods for determining the confined-explosion gas pressure was that the variation in C_v with temperature was neglected. Given in the literature, reference (20), are equations relating the specific heat at constant pressure, C_p, with temperature for the various component gases in the final gas mixture. With the assumption that the perfect gas relation

$$R_o = C_p - C_v \quad (R_o = \text{universal gas constant})$$

can be used, equation (5.1) becomes

$$\Delta Q = n\,(C_p - R_o)\Delta T \tag{5.2}$$

and direct use of the C_p equations in reference (20) can be made For convenience in calculation, the computer finds a weighted average C_p to be used in equation (5.2) with the total number of moles of gas, n, in the final mixture.

With the total energy released, Q, and the total number of moles, n, of the gas mixture known, the computer uses the following numerical procedure to determine the final temperature of the gas mixture. (The initial temperature is taken at $T = T_a$ and the addition of Q follows a constant volume process.) (1) The weighted average C_p for the gas mixture is determined for the temperature, T. (2) For a temperature step of $\Delta T = 100°F$, the incremental amount of heat, ΔQ, required to change the temperature by 100°F is calculated from equation (5.2). (3) The temperature of the gas mixture after the step is $T = T + \Delta T$. (4) The incremental energy, ΔQ, is subtracted from the total released energy, Q. (5) The calculational steps (1) through (4) continue until all of the total released energy, Q, is used, thus the final temperature, T_f, is calculated.

With the final temperature, T_f, determined, the perfect gas law gives the final pressure of the gas mixture in the closed volume, V_o, by the relation

$$P_f = n\, R_o T_f / V_o \tag{5.3}$$

Conventionally this pressure is expressed as an overpressure, so that the confined-explosion gas pressure, P_g, is defined as

$$\Delta P_g = P_f - P_a \tag{5.4}$$

It should be restated that this method of calculating the confined-explosion gas pressure is limited here to C-H-N-O type explosives with aluminum as the only possible metallic additive. Since most common explosives used as fills in conventional weapons fall into this category, this limitation is not considered restrictive to the general use of this computer program. Also this improved method should yield conservative results because optimum mixing and the most efficient chemical reactions are assumed.

Comparison with Experimental Data. Attention is now directed to the adequacy of this improved method. In Figure 5.2 Weibull's TNT data from reference (19) are plotted as indicated by circles. The computer code predictions are given as the solid curve. We note that the agreement with the data is excellent, that the change in slope of the predicted curve follows the general behavior of the data, and that

the data falls either on the curve or slightly below it which demonstrates the conservatism of the new method. From this comparison alone, it is concluded that this technique is far superior to the existing methods of calculating the confined-explosion gas pressure for TNT.

Before assuming the generality of this improved method, it is necessary to make comparisons with experimental data from different explosive mixtures and different initial ambient air conditions. The next most complete set of data is found in reference (21) for a RDX/WAX, 89.5/10.5 mixture detonated in air at sea level conditions. A plot of the data points (circles) from this study and the code predictions (solid curve) are given in Figure 5.3. Again the excellent agreement and the conservatism of the improved method predictions are noted. Reference (21) also gives data for this same RDX/WAX mixture for a reduced atmosphere (P_a = 1 psia). These data and the code predictions are given in Figure 5.4, and the same excellent agreement and conservatism are demonstrated.

Other assorted data for different explosives were found in reference (21), and some aluminized explosive data were found in reference (17)--all for sea level conditions. There was an insufficient quantity of these data to construct curves, thus they are tabulated in Table 5.1 along with calculated code predictions. The excellent agreement is again noted, especially for the extremely high-pressure PETN data and the aluminized RDX data. An interesting observation can be made with the aluminized data. As the percentage of aluminum increases, the overprediction of the confined-explosion gas pressuure tends to increase. But even for the unrealistic mixture containing 50% aluminum, there is only a 16% deviation. This increase is believed due to the assumed optimum mixing and most efficient reaction in the code. Evidently the aluminum is not able to utilize the oxygen in the surrounding air to the maximum extent assumed in the code calculation.

It is concluded from these comparisons that the improved method for calculating the confined-explosion gas pressure is far superior to any other known existing technique. Even with the use of perhaps a not-too-realistic combustion type model and the liberal use of

equilibrium perfect gas relations and properties for high-pressure and temperature transient conditions, the improved method appears to perform exceptionally well. From these comparisons the method appears capable of handling mono, composite, and aluminized explosives at sea level ambient conditions and reduced atmospheric ambient conditions. Therefore with justifiable confidence, this improved method is used as the basis for confined-explosion gas pressure calculations in the computer program.

Although use of this computer program has been consistently limited to C-H-N-O explosives with aluminum as the only possible metallic additive, there is no theoretical reason why it cannot be adjusted to perform well with other metallic additives or non-C-H-N-O explosives. This limitation arises only because there exists no experimental data on confined-explosion gas pressure for these different explosives that will permit the establishment of a set of reaction priorities similar to those for C-H-N-O explosives.

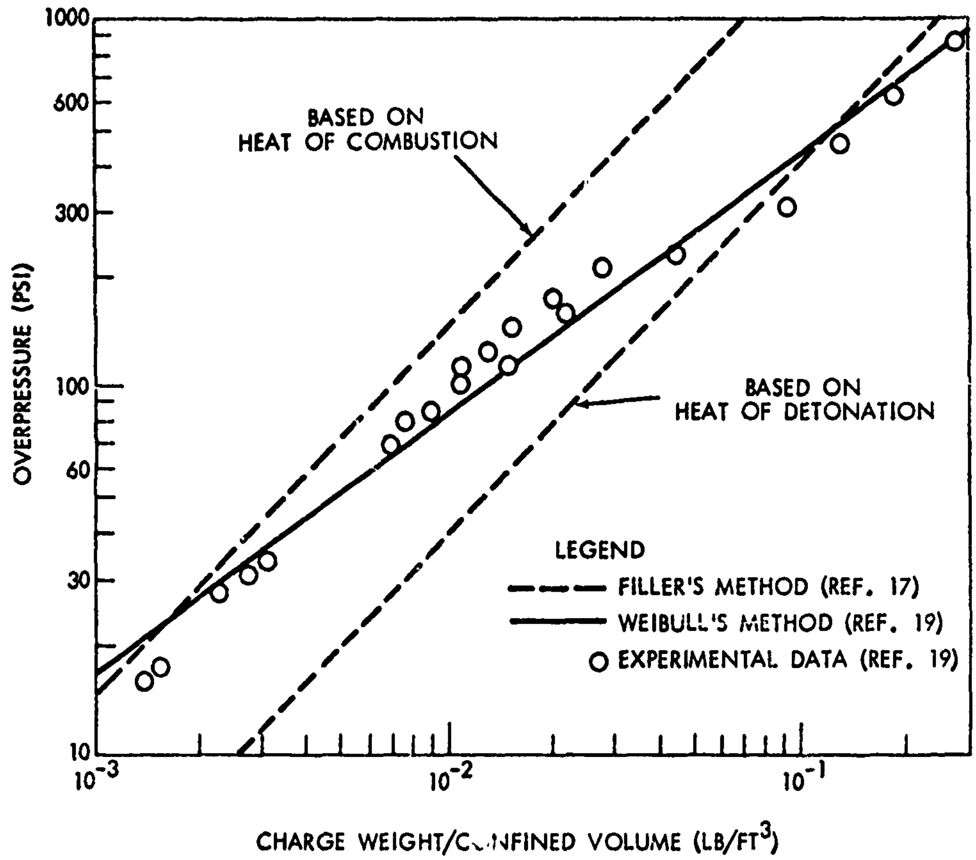


FIG. 5.1 COMPARISON OF EXISTING METHODS FOR PREDICTING CONFINED-EXPLOSION GAS PRESSURE WITH EXPERIMENTAL DATA FOR TNT EXPLOSIONS IN AIR AT SEA LEVEL CONDITIONS

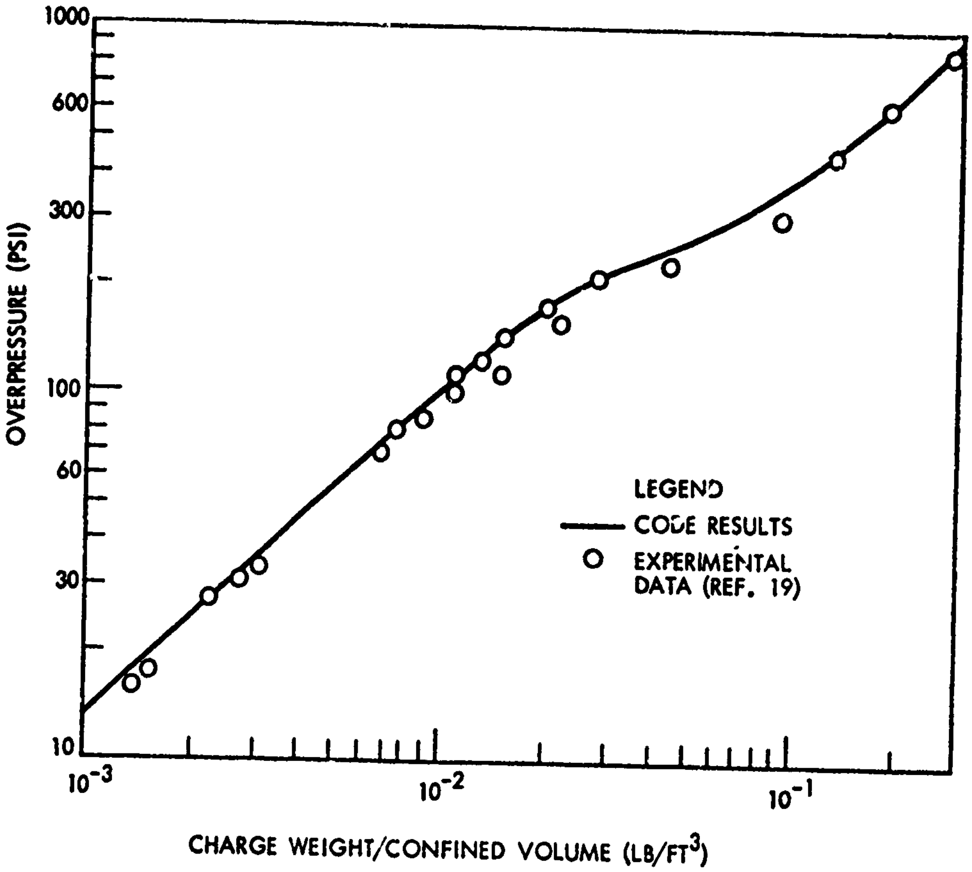


FIG. 5.2 CODE RESULTS FOR CONFINED-EXPLOSION GAS PRESSURE FOR TNT IN AIR AT SEA LEVEL

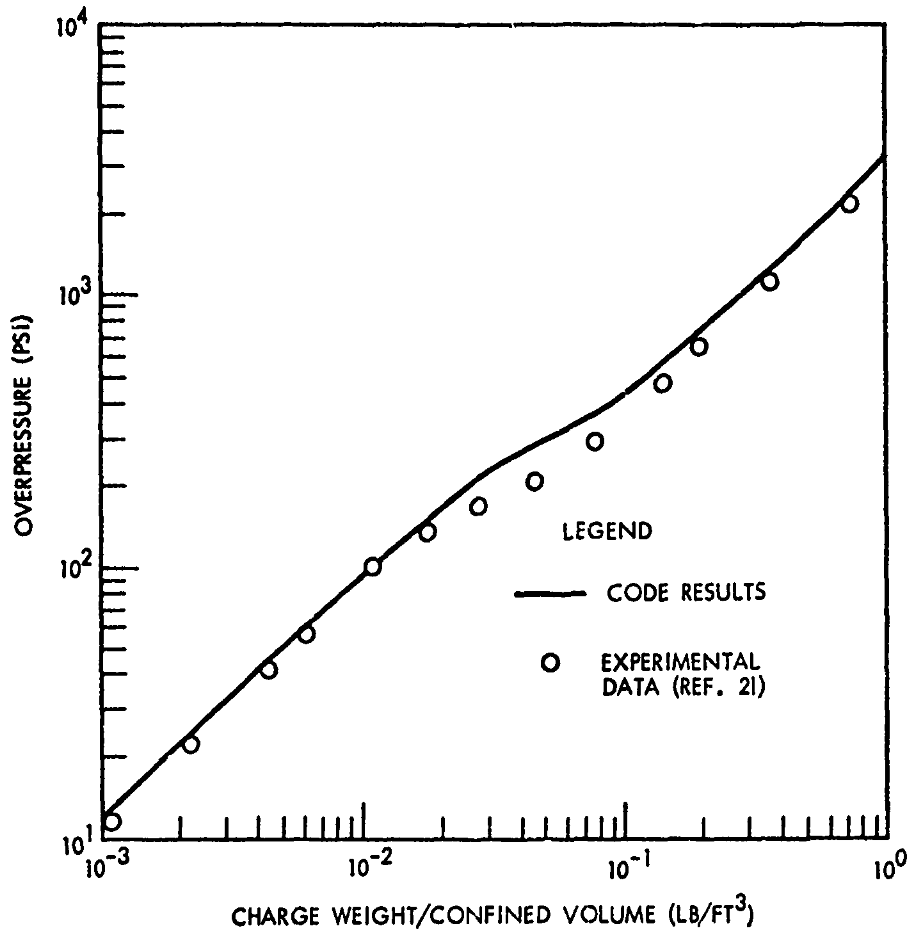


FIG. 5.3 CODE RESULTS FOR CONFINED-EXPLOSION GAS PRESSURE FOR RDX/WAX, 89.5/10.5 IN AIR AT SEA LEVEL

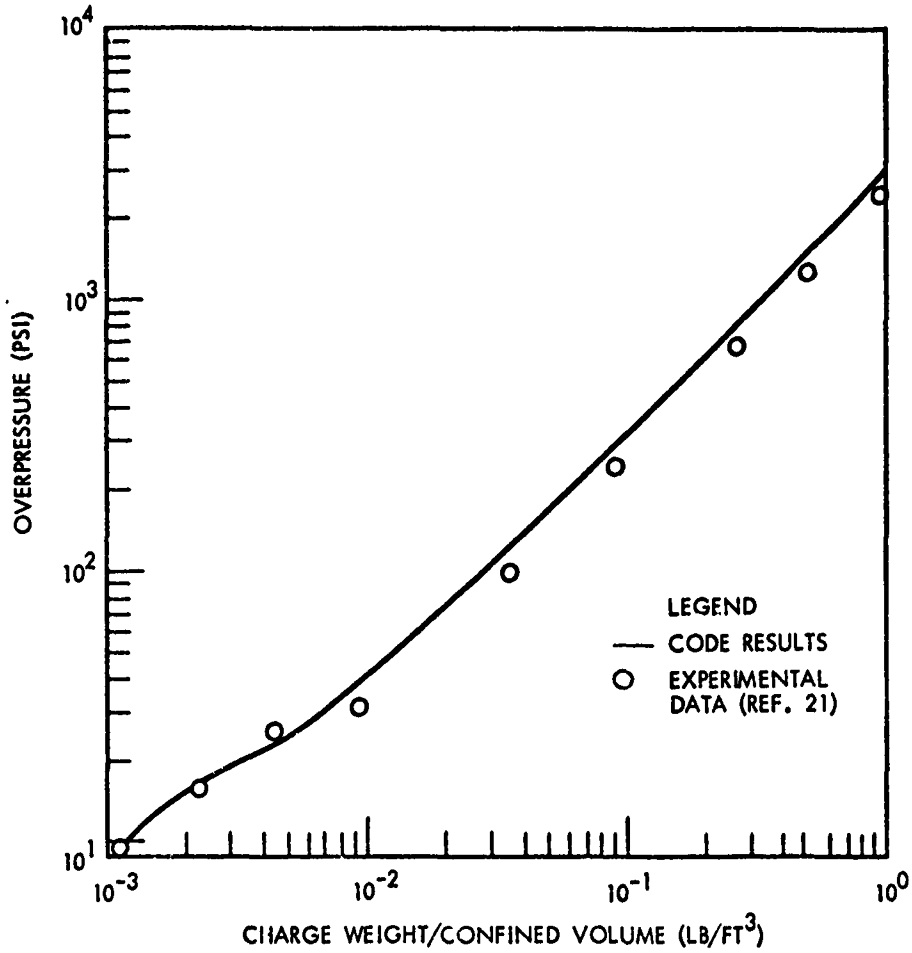


FIG. 5.4 CODE RESULTS FOR CONFINED-EXPLOSION GAS PRESSURE FOR RDX/WAX, 89.5/10.5 IN AIR AT P = 1 PSI

TABLE 5.1
MISCELLANEOUS CONFINED-EXPLOSION
GAS PRESSURE DATA

TYPE OF EXPLOSIVE	W/V (LB/FT^3)	CALCULATED OVERPRESSURE (PSI)	EXPERIMENTAL OVERPRESSURE (PSI)	DEVIATION (%)
RDX/TNT				
60/40	0.00221	22.0	19.9	+10
60/40	0.00442	41.0	38.3	+ 7
PETN	0.182	711	725	−2
PETN	0.304	1089	1110	−2
PETN	0.405	1405	1400	+ 0
RDX/AL/WAX				
98/ 0/2	0.00171	15.3	15.6	−2
76/22/2	0.00171	22.0	21.3	+ 3
63/35/2	0.00171	26.6	24.3	+ 9
48/50/2	0.00171	30.3	26.0	+16

DATA FROM REFS. 17 AND 21

CHAPTER 6

VENTING CALCULATIONS

Venting. Inherent in the preceding section was the assumption of a completely closed structure, i.e., no venting occurs before the maximum value of the confined-explosion gas pressure is established. Therefore, at the onset of venting the initial conditions of the confined-explosion gas pressure are known from previous calculations; P_f (gas pressure in absolute units), T_f (temperature), n (total number of moles of gas), C_p (average specific heat of gas at T_f), and V_o (volume of gas). A combination of n, V_o, and the molecular weights of the gas mixture components yields the initial density, ρ_f, of the gas mixture. Gamma, γ, (the ratio of specific heats), is found with the known value of C_p from the perfect gas relation

$$\gamma = C_p/C_v = C_p/(R_o - C_p) \tag{6.1}$$

From code input information, the constant backpressure, P_b, against which venting occurs and the initial vent area, A_o, are given.

The relations governing the venting process have been derived in reference (22) for steady isentropic flow through a perfect nozzle. In this reference, γ was taken to be 1.4 which permitted the relations to be expressed in closed form. However, since γ in this computer program is not 1.4 and is not constant, the differential form of these governing equations are taken from reference (22). (There is a typographical error in equation (15) of reference (22)--(γ - 1) in the denominator should be (γ + 1).) These governing equations are:

for sonic flow

$$\frac{\Delta P_1}{P_1^{\frac{3\gamma-1}{2\gamma}}} = \left[g\ \gamma^3\ (P_o{}^{1/\gamma}/\rho_o)\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}} \right]^{1/2} \frac{A_o}{V_o}\ \Delta t \tag{6.2}$$

$$\text{for } P_1 \geq \frac{P_b}{\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}}$$

for subsonic flow

$$\frac{P_1^{-\frac{\gamma-1}{\gamma}} \Delta P_1}{\left(P_1^{\frac{\gamma-1}{\gamma}} - P_b^{\frac{\gamma-1}{\gamma}}\right)^{1/2}} = \left[g\ \gamma^3 \left(\frac{2}{\gamma-1}\right)\left(\frac{P_o\ \ P_b{}^2}{\rho_o{}^\gamma}\right)^{1/\gamma}\right]^{1/2} \frac{A_o}{V_o} \Delta t \tag{6.3}$$

$$\text{for } P_b < P_1 < \frac{P_b}{\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}}$$

Throughout the venting process, these isentropic relations are assumed

$$T_1 = T_o\ (P_1/P_o)^{(\gamma-1)/\gamma} \tag{6.4}$$

$$\rho_1 = \rho_o\ (P_1/P_o)^{1/\gamma} \tag{6.5}$$

The terms are defined as follows

$\Delta P_1 = (P_o - P_1)$ = arbitrary pressure step increment

P_o = pressure at beginning of increment step

P_1 = pressure at end of increment step

P_b = ambient backpressure (constant throughout venting)

g = acceleration due to gravity

γ = specific heat ratio given by equation (6.1) (based on T_o and assumed constant during increment step)

ρ_o = density at beginning of increment step

ρ_1 = density at end of increment step

T_o = temperature at beginning of increment step

T_1 = temperature at end of increment step

V_o = volume of structure (constant)

A_o = vent area (constant)

Δt = time increment (parameter to be determined)

Even though the relations are derived for steady flow, it is assumed that they are applicable to the venting problem because the pressure step used in the numerical solution of these equations is sufficiently small that gas mixture properties can be considered constant during a single incremental step.

It is assumed in the venting process that the composition of the gas mixture remains constant, i.e., no single component of the gas mixture is vented preferentially. The pressure increment step used in the computer program is defined as

$$\Delta P_1 = (P_f - P_b)/100 \tag{6.6}$$

i.e., there are 100 pressure increment steps. Even though the computer performs 100 steps in this calculation, only every tenth step is printed as output. The printout can be increased to up to every other step if desired. During the venting process as the gas density is decreasing, the computer keeps a running account of the quantities of each component of the gas mixture remaining in the compartment structure. The need for this procedure will become apparent in subsequent sections.

The following discussion is a description of a typical venting calculation. (1) Starting values of P_o, ρ_o, T_o, γ, A_o, V_o, and P_b are known. (2) From the pressure increment step, P_1 is calculated and used to determine if flow is sonic or subsonic. (3) With the proper equation (6.2) or (6.3) chosen, the time increment Δt is determined, and from $t_1 = t_o + \Delta t$ the absolute time from beginning of venting associated with P_1 is found. (4) From equations (6.4) and (6.5) the temperature and density at the end of the increment step are determined. (5) From the density the number of moles of gas mixture components remaining in the compartment are found. (6) From the temperature, a new average C_p is calculated from which a new γ is determined. (7) Values at the end of this increment step, P_1, T_1, ρ_1, and new γ,

become the beginning values P_o, T_o, ρ_o, and γ for the next step. (8) The above procedures form a loop that continues until the 99th increment step is completed which is the step immediately before $P_1 = P_b$. The program is stopped here because equation (6.3) cannot be solved for $P_1 = P_b$.

Vent Area and Volume Changes. The orderly procedure given above can be readily interrupted to accommodate vent area and volume changes in accordance with input failure criteria controlling damage propagation. By constantly monitoring the pressure-time history of the venting process, the computer can easily adjust to changes from input of the type presented in Figure 3.1. For a given pressure or time, an adjustment in vent area can be made simply by changing the value A_o in equations (6.2) and (6.3). However, a volume change requires not only the change of V_o in equations (6.2) and (6.3) but also an adjustment in the gas mixture pressure because the volume has changed.

Upon wall failure in the initial compartment, it is assumed that the gas mixture in the initial compartment instantaneously mixes and comes to equilibrium with the air in the newly available compartment. The conservation of energy states for this process that the sum of the internal energy of the gas mixture immediately prior to wall failure and the internal energy of the air contained in the adjacent compartment is equal to the internal energy of the new gas mixture after the mixing process. (No further chemical reaction is assumed to occur.) In equation form, this concept is stated as

$$\frac{P_1 V_o}{(\gamma_1 - 1)} + \frac{P_a V_a}{(\gamma_a - 1)} = \frac{P_2\ (V_o + V_a)}{(\gamma_2 - 1)} \tag{6.7}$$

where P_1 = pressure of gas mixture immediately prior to wall failure

γ_1 = gamma of gas mixture immediately prior to wall failure

V_o = volume of gas mixture immediately prior to wall failure

P_a = ambient pressure of air in adjacent compartment

V_a = volume of air in adjacent compartment

γ_a = gamma of air (taken to be 1.4)

P_2 = pressure of new gas mixture

γ_2 = gamma of new gas mixture

Unfortunately there are two unknowns in equation (6.7), P_2 and γ_2. (γ_2 is unknown because the gas composition and temperature have changed.)

By keeping a running account of the amounts of the components of the gas mixture before wall failure and by calculating the amount of oxygen and nitrogen in the air in the new compartment, the computer calculates the composition of the new gas mixture and finds the total number of moles of the new gas mixture, n_2. Since the new volume $(V_o + V_a)$ is known, the new density, ρ_2, is calculated. The perfect gas law

$$P_2 = (n_2 R_o T_2)/(V_o + V_a) \tag{6.8}$$

gives a second relation but introduces the third variable, T_2. From the programmed C_p equations as a function of temperature for the gas components, the computer is capable of generating a third relation from the known quantities of the gas components in the new mixture

$$\gamma_2 = \gamma_2(T_2) \text{ (based on equation (6.1))} \tag{6.9}$$

The numerical iteration solution of equations (6.7)--(6.9) gives the values of P_2, T_2, and γ_2. Since ρ_2, n_2, and the new gas mixture components are known, all of these values become the beginning parameters for the next increment step in the venting calculation method. Subsequent wall failures controlled by input damage criteria are treated in this same manner.

Verification. There are no experimental data available to verify this entire venting process including vent area and volume changes. There are only limited data applicable to the venting process without area and volume changes. These are given in reference (22) from which the venting equations were taken. Here venting of the confined-explosion gas pressure from a test facility at NOL was measured. Venting gases escaped the test chamber of the facility through a

"S" shaped labyrinth passageway out either a partially open door (small vent area) or an open door (medium vent area). Agreement between equation predictions and experimental data was very good for the small vent area where flow in the passageway was probably sufficiently slow not to induce any type of flow losses. Agreement for the medium vent area, which was about seven times greater than the small vent area, was only fair with the equations underpredicting vent times by 20 to 30%. It is believed that the seven-fold increase in vent area produced relatively high flow velocities in the passageway from which significant losses slowed the venting process.

In reference (22) caution is expressed in using these venting relations for large vent areas. However, it has been learned that limited unpublished data* from the Naval Ship Research and Development Center (NSRDC) on venting explosion gases through large openings agree very well with predictions from the venting equations. Therefore, with only limited confirmation of the venting procedure, this method is employed in the computer code for predicting the pressure-time history of the confined gas mixture.

Limitations. The venting section of the computer code has not been verified experimentally to any significant degree. Thus experimental evidence in this area is needed to assign a confidence level to this section equivalent to that of the shock and confined-explosion gas pressure sections. Four assumptions are made in this section that need additional study. First, heat losses to the surrounding walls are neglected as a significant mechanism to reduce the gas mixture pressure. Second, a constant backpressure against which venting must occur is assumed. Third, gas mixing and the establishment of pressure equilibrium occur instantaneously with compartment wall failure. Fourth, no chemical reactions occur with the air in the adjacent compartments after wall failures. In terms of the small compartments in aircraft wings and significant venting to the atmosphere, none of these assumptions are believed to be restrictive for aircraft applications. However, for large explosions and large structures such as ship

*Information received from J. W. Sykes (NSRDC).

compartments or building rooms, they may indeed be restrictive and may require additional study and modification. The code is constructed in a manner such that modifications in these areas can be easily accommodated.

CHAPTER 7

USER'S GUIDE

Computer Requirements. The computer program is written in FORTRAN for a CDC 6400 computer, and it should work without change on other CDC machines. The program is straightforward and can be adapted easily to other computers. The major change that may have to be made is the spreading out onto individual cards of the statements that are now placed on a single card and separated by the $ sign. Storage requires less than 32,000 core memory words, the compilation time is about 15 seconds, and the run time for a single case is about 1 second on the CDC 6400.

Program Structure. A complete flow diagram of the computer program is given in Appendix A. Detail descriptions of the input cards and format are given in Appendix B. A complete list of the program variables with their definitions are given in Appendix C. The code consists of the main program BLAST and six subroutines. The functions of these sections are as follows:

- BLAST: reads input data; does venting calculation; does final portion of the shock wave calculation
- MIX: supplies new conditions (pressure, volume, temperature, gamma) after the gases of two compartments are mixed.
- HEDATA: contains tables of properties of explosive components and mixtures.
- GAMMA: supplies average specific heat ratio and internal energy for a gas of given composition and temperature.
- GASES: supplies initial conditions in the compartment immediately after the explosion occurs and the confined-explosion gas pressure is developed.

TNT: supplies pressure, distance, arrival time, and other data for a spherical 1-lb TNT free-field explosion at sea level.

ARDC: gives standard-atmosphere pressure and temperature for a desired atltitude.

A complete listing of the entire program is given in Appendix D.

Printed Warnings in Output. During the running of a problem with this computer program, printed diagnostic or warning statements may appear in the output to alert the user. These are:

(1) "WFACT NOT KNOWN, 1.0 IS USED."

This means that no energy equivalent weight has been supplied for the shock wave calculation with the desired explosive. The program assumes a value of 1.0, thus results are equal to those of TNT.

(2) "CHARGE SHAPE CORRECTION IS CRUDE. PSI EXCEEDS RANGE OF EXPERIMENTAL DATA."

The cylindrical charge equivalent weight depends on the peak shock pressure level. Above 100 psi, no experimental data were available for correlation and theoretical techniques were used. The warning statement is printed to indicate that shock data for the particular case under study are approximations.

(3) "CASE WEIGHT CORRECTION IS CRUDE. PSI EXCEEDS RANGE OF EXPERIMENTAL DATA."

The method for calculating the casing equivalent weight was based on pressure data for 100 psi and below. The warning statement is printed to indicate that shock data for the particular case under study are approximations because the peak overpressure exceeds 100 psi.

(4) "CAUTION--CONTACT SURFACE HAS ARRIVED. DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL =."

This warning statement appears during the shock calculations if the contact surface reaches the desired distance being investigated. It indicates that, after the indicated time, the shock data are approximations.

Changes to the Program. There are several items in the computer program that probably will be frequently changed by the user depending upon the problem under consideration. They involve the addition of new explosives to the data table in the program and changes in the amount of printout for the shock and venting calculations. If a new explosive not in the data bank is frequently used, the user may wish to add it permanently to the subroutine HEDATA. There is room for 11 new explosives in this table. Beginning with index number 30 (card HEDA0675), four data cards using the format for the existing explosives can be inserted to input the new explosive.

The amount of printout desired for shock and venting calculations may vary with the area of interest for a particular problem. This is easily changed by varying KMAX1 for shock calculations or KMAX2 for venting calculations on card BLAS0560. The shock wave calculation is done in KMAX1 steps in time, equally spaced within the positive duration of the overpressure. The built-in value of KMAX1 is 10. If more printout is desired, change KMAX1 to 20 or 40. If more than 40 lines are desired, the dimensions of PSI(40), T1(40), T2(40), and PSIREF(40) must be increased. Values of KMAX1 below 10 are not recommended because the numerical integration to obtain impulse is controlled by the number of these steps.

The venting calculations are performed in 100 fixed integration steps. However, only every KMAX2-th step is printed as output. The built-in value of KMAX2 is 10, giving 10 lines of venting printout. If more venting data is desired, KMAX2 can be changed to 5, 4, or 2.

Example Problems. To demonstrate the use of the computer code with its different options and features, nine sample problems have been run. They are variations of the following base problem.

> Consider an 8 ft^3 compartment. A projectile has penetrated the compartment forming an opening of 0.00545 ft^2 area. The projectile contains 0.0294 lb of explosive of composition 74% RDX, 21% AL, and 5% WAX. It has a length to diameter ratio of 2.7 and a case weight to charge weight ratio of 4.24.

Figure 7.1 shows the input cards for the nine problems that have been solved. (Appendix B gives the description and format of input data cards.) Examples 1-3 show the three ways to specify the explosive.

Examples 5-7 show the three options specifying damage criteria for wall failure in the venting calculations. Example 8 shows the method of a shock wave calculation with several distances specified. Examples 4 and 9 demonstrate problems at an altitude other than sea level. Specific descriptions of each example are given in the following paragraphs.

Example 1 involves only one input card. The explosive number is 17, indicating the number of the desired explosive in the list of subroutine HEDATA. At the end of the card, NOPT=1 indicates that only a venting calculation is desired; NV=0 indicates that the chamber volume and vent area remain at their initial values throughout the problem; and NR=0 indicates that no distances are specified since this is only a venting calculation. The results of this problem are shown in Figure 7.2.

Example 2 involves two data cards. The first card is the same as in Example 1 except that the explosive number is 0. This causes the second card to be read in. This card gives the energy equivalent weight = 1.30, the heat of formation = 29.36 cal/gm, and the weight fractions of C, H, O, N, and AL. The results are the same as for Example 1 which are given in Figure 7.2.

Example 3 again involves two data cards. The first card has an explosive number of -1. This causes the second card to be read in. This card gives the energy equivalent weight = 1.30 and the weight fractions of the desired components from the explosive list in HEDATA: 74% number 27 (RDX), 21% number 25 (AL), and 5% number 26 (WAX). Again, the results are the same as those of Example 1 which are given in Figure 7.2.

Example 4 is the same as Example 1 except that the compartment is at altitude rather than at sea level. The ambient pressure is 6.76 psia and the temperature is -24.6°C. The results of this calculation are shown in Figure 7.3.

Example 5 returns to sea level but the compartment volume is allowed to change. NV=1 means that one card of volume and area change data is to be read. This card contains the following data; if the confined-explosion gas pressure in the tank exceeds 30 psia, the volume increases by 4 ft^3 and the vent area increases 0.00545 ft^2.

The ambient pressure and temperature of the air in this additional volume and vent area are added only if the confined-explosion gas pressure exceeds the 45-psia level. The results are shown in Figure 7.4.

Example 6 has two cards of volume and area change data. The last number on these cards is 2 which indicates that the changes of volume and area are to be made at the indicated times of 0.15 and 0.60 sec. No tests are made on the pressure, so that the changes are made at the indicated times regardless of the pressure. The results are shown in Figure 7.5.

Example 7 has three cards of volume and area data. The last number on these cards is 3 which indicates that if the pressure exceeds the indicated value when the indicated time is reached, then the volume and area change is made. For example, if the pressure in the tank exceeds 45 psia at 0.15 sec, 4 ft^3 of volume and 0.00545 ft^2 of vent area are added. The results are shown in Figure 7.6.

Example 8 is a shock wave calculation only, indicated by NOPT=2. NV=0 since no venting parameters are involved in a shock wave calculation, and NR=3 since three distances are desired. The second card contains these three distances: 0.667, 1.000, and 1.333 feet from the center of the charge. The results for the single distance of 0.667 are shown in Figure 7.7.

Example 9 is the same as Example 8 except that the compartment is at altitude. The results are shown in Figure 7.8.

Explanation of Typical Output. A typical example of the printout for shock calculations is given in Figure 7.7 which are the results from Example 8. The index number and properties of the explosive used in the calculation appear at the beginning of the output. The two warning statements concerning the cylindrical charge equivalent weight and casing equivalent weight are noted. Under "SHOCK WAVE CALCULATION", the left-hand column repeats all the input parameters governing the shock problem. In the right-hand column, certain constants derived by the computer for the calculation are given:

ADJUSTED WT(LB TNT)--equivalent TNT sphere from equation (4.10)

HE ENERGY FACTOR--energy equivalent weight, f_e, from Table 3.1

CHARGE WEIGHT FACTOR	cylindrical charge equivalent weight, f_s, from Figure 4.5
CASE WEIGHT FACTOR	casing equivalent weight, f_c, from equation (4.8) or (4.9)
PRESSURE SCALE FACTOR	(P_s/P_a) for equations (4.2)--(4.5)
DISTANCE SCALE FACTOR	$(W_s/W_a)^{1/3}\ (P_a/P_s)^{1/3}$ for equations (4.2)--(4.5)
TIME SCALE FACTOR	$(W_s/W_a)^{1/3}\ (P_a/P_s)^{1/3}\ (T_a/T_s)^{1/2}$ for equations (4.2)--(4.5)
NORMAL REFL FACTOR	normal reflection factor, f_R, from equations (4.11)--(4.13)

The tabulated pressure-time shock data is noted for the desired distance of 0.667 ft. Both the incident and normally reflected overpressures are given as functions of time where time is measured from the instant of detonation and shock arrival. For example, the shock arrives at the distance 0.667 ft in 0.07118 msec; the peak incident overpressure is 317.6 psi and the reflected overpressure is 2144 psi; and the positive phase of the shock is completed 0.192 msec after detonation or 0.1209 msec after shock arrival. Next the impulses for the incident and reflected waves are given. Lastly, the warning statement concerning the contact surface appears which states that 0.02787 msec after the shock arrives, the pressure-time data are approximations.

Figure 7.6 gives printout results for Example 7 on the confined-explosion gas pressure venting and subsequent changes due to structural failures. At the beginning of the output are the index number and properties of the explosive used in the calculation. Under "VENTING CALCULATION" a repeat of input parameters is given; under "BEGIN VENTING CALCULATION" the input failure criteria table is repeated. Under "PROPERTIES OF GASES" the output describes the condition of the confined-explosion gas in the initial compartment volume before any venting has occurred. The first statement indicates that oxidation was complete, i.e., sufficient oxygen was available to make H_2O, AL_2O_3, and only CO_2. Had there been insufficient oxygen for complete oxidation, the output would have indicated the name and quantity of the last product formed. For example, if all $H \rightarrow H_2O$

and AL → AL_2O_3 but there was insufficient oxygen to completely react with all the C to form CO, the computer would print "PERCENT LAST PRODUCT (CO) = (fraction of carbon used)". Next, the computer prints the maximum temperature of the confined-explosion gas, the energy released in the chemical reaction that creates the confined-explosion gas pressure, the specific heat ratio, γ, and the maximum value of the confined-explosion gas pressure expressed as an overpressure.

Under "BEGIN VENTING OF GASES" the gas pressure-time data are tabulated along with the amount of gas in the confining volume (GASES), the temperature of the gas (TEMP), the specific heat ratio (GAMMA), and an index (NEQN). If this index is 1 then the flow velocity is sonic; if 2, flow velocity is subsonic. The beginning time is zero for this calculation which is set arbitrarily after the dissipation of the shock wave, and the overpressure is maximum at 45.9 psi. Adjustments made with compartment failures and continued venting are noted. For example, at t=0.15 sec the gas overpressure is 36.5 psi which is above 45 psia and the wall fails. A new pressure of 36.75 psia or 22 psi overpressure is calculated for the new volume of 12 ft^3, and venting continues through the new area of 0.0109 ft^2 until t=0.6 sec when another failure occurs. The code readjusts the pressure to accommodate the new volume and venting continues until the overpressure is essentially zero at t=0.9 sec.

ITEMS ON FIRST DATA DATA CARD

EXPLOSIVE WEIGHT | EXPLOSIVE NUMBER | L/D | M/C | V_o | A_o | P_b | T_b | ALTITUDE | P_a | T_a | NOPT | NV | NR

```
EXAMPLE 1
.0294    17   2.7 4.24   8. 545-3 14.7   20.     0. 14.7   20.     1     0     0

EXAMPLE 2
.0294     0   2.7 4.24   8. 545-3 14.7   20.     0. 14.7   20.     1     0     0
   1.30  29.36    .163     .027   .280     .320    .210

EXAMPLE 3
.0294    -1   2.7 4.24   8. 545-3 14.7   20.     0. 14.7   20.     1     0     0
   1.30 27 .74 25 .21 26 .05

EXAMPLE 4
.0294    17   2.7 4.24   8. 545-3 6.76-24.6      0. 6.76-24.6      1     0     0

EXAMPLE 5
.0294    17   2.7 4.24   8. 545-3 14.7   20.     0. 14.7   20.     1     1     0
    30.       0.      4. .545-2   14.7     20.       1

EXAMPLE 6
.0294    17   2.7 4.24   8. 545-3 14.7   20.     0. 14.7   20.     1     2     0
     0.      .15      4. .545-2   14.7     20.       2
     0.      .60      4. .545-2   14.7     20.       2

EXAMPLE 7
.0294    17   2.7 4.24   8. 545-3 14.7   20.     0. 14.7   20.     1     3     0
    45.      .15      4. .545-2   14.7     20.       3
    20.      .6       4. .545-2   14.7     20.       3
    19.      .8       4.     0.   14.7     20.       3

EXAMPLE 8
.0294    17   2.7 4.24   8. 545-3 14.7   20.     0. 14.7   20.     2     0     3
   .667    1.0  1.333

EXAMPLE 9
.0294    17   2.7 4.24   8. 545-3 6.76-24.6      0. 6.76-24.6      2     0     3
   .667    1.0  1.333
```

FIG. 7.1 INPUT CARDS FOR NINE EXAMPLE PROBLEMS

```
INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1972
RDX/AL/WAX, 74/21/5

EXPLOSIVE PROPERTIES
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G      C     H     N     O    AL
  17  1.300 .029360   .163  .027  .280  .320  .210

VENTING CALCULATION

CHARGE WEIGHT(LB)       =   .2940E-01
INIT VOLUME(CU FT)      =   8.000
INIT VENT AREA(SQ FT)   =   .5450E-02
AMBIENT PRESSURE(PSIA)  =   14.70
AMBIENT TEMP(C)         =   20.00
CHAMBER PRESSURE(PSIA)  =   14.70
CHAMBER TEMP(C)         =   20.00
NOPT=  1  NV=  0

BEGIN VENTING CALCULATION

PROPERTIES OF GASES--
OXIDATION COMPLETE
TEMPERATURE, DEGREES F  =  1653.2
ENERGY RELEASE(KCAL/G)  =  3.6573
SPECIFIC HEAT RATIO     =  1.3141
GAS OVERPRESSURE(PSI)   =  45.945

BEGIN VENTING OF GASES
OVERPR(PSI)  TIME(SEC)      GASES(LB)    TEMP(R)    GAMMA NEQN
   45.94      0.             .6167       2113.      1.3141
   41.35       .6936E-01     .5809       2074.      1.3155   1
   36.76       .1453         .5443       2032.      1.3167   1
   32.16       .2293         .5070       1986.      1.3181   1
   27.57       .3229         .4689       1937.      1.3197   1
   22.97       .4285         .4297       1884.      1.3214   1
   18.38       .5496         .3895       1825.      1.3235   1
   13.78       .6911         .3479       1759.      1.3259   1
   12.47       .7360         .3358       1739.      1.3267   1
   7.880       .9175         .2921       1661.      1.3298   2
   3.286      1.171          .2462       1570.      1.3338   2
    .6943E-01 1.690          .2125       1494.      1.3380   2
```

FIG. 7.2 OUTPUT RESULTS FOR EXAMPLES 1, 2, AND 3

INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1972
RDX/AL/WAX, 74/21/5

EXPLOSIVE PROPERTIES

NUMBER	EQWT	EFORM KCAL/G	EXPLOSIVE COMPOSITION BY WEIGHT C	H	N	O	AL
17	1.300	.029360	.163	.027	.280	.320	.210

VENTING CALCULATION

CHARGE WEIGHT(LB) = .2940E-01
INIT VOLUME(CU FT) = 8.000
INIT VENT AREA(SQ FT) = .5450E-02
AMBIENT PRESSURE(PSIA) = 6.760
AMBIENT TEMP(C) = -24.60
CHAMBER PRESSURE(PSIA) = 6.760
CHAMBER TEMP(C) = -24.60
NOPT= 1 NV= 0

BEGIN VENTING CALCULATION

PROPERTIES OF GASES--
OXIDATION COMPLETE
TEMPERATURE, DEGREES F = 2655.7
ENERGY RELEASE(KCAL/G) = 3.6573
SPECIFIC HEAT RATIO = 1.2893
GAS OVERPRESSURE(PSI) = 42.914

BEGIN VENTING OF GASES

OVERPR(PSI)	TIME(SEC)	GASES(LB)	TEMP(R)	GAMMA	NEQN
42.91	0.	.3426	3116.	1.2893	
38.62	.6729E-01	.3194	3053.	1.2905	1
34.33	.1420	.2958	2985.	1.2915	1
30.04	.2260	.2716	2912.	1.2926	1
25.75	.3215	.2468	2831.	1.2939	1
21.46	.4323	.2212	2741.	1.2953	1
17.17	.5635	.1948	2640.	1.2971	1
12.87	.7241	.1673	2523.	1.2993	1
8.583	.9296	.1384	2383.	1.3022	1
5.647	1.111	.1176	2268.	1.3049	1
1.356	1.524	.8499E-01	2052.	1.3104	2
.6846E-01	1.968	.7451E-01	1970.	1.3137	2

FIG. 7.3 OUTPUT RESULTS FOR EXAMPLE 4

INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1972
RDX/AL/WAX, 74/21/5

EXPLOSIVE PROPERTIES

NUMBER	EQWT	EFORM KCAL/G	C	H	N	O	AL
17	1.300	.029360	.163	.027	.280	.320	.210

(EXPLOSIVE COMPOSITION BY WEIGHT: C, H, N, O, AL)

VENTING CALCULATION

CHARGE WEIGHT(LB) = .2940E-01
INIT VOLUME(CU FT) = 8.000
INIT VENT AREA(SQ FT) = .5450E-02
AMBIENT PRESSURE(PSIA)= 14.70
AMBIENT TEMP(C) = 20.00
CHAMBER PRESSURE(PSIA)= 14.70
CHAMBER TEMP(C) = 20.00
NOPT= 1 NV= 1

BEGIN VENTING CALCULATION

TABLE OF VOLUME AND VENT AREA CHANGES

P(PSIA)	T(SEC)	V(CU FT)	A(SQ FT)	PAMB(PSIA)	TAMB(C)	NOPTV
30.00	0.	4.000	.5450E-02	14.70	20.00	1

PROPERTIES OF GASES--
OXIDATION COMPLETE
TEMPERATURE, DEGREES F = 1653.2
ENERGY RELEASE(KCAL/G) = 3.6573
SPECIFIC HEAT RATIO = 1.3141
GAS OVERPRESSURE(PSI) = 45.945

FAILURE LEVEL IN TABLE EXCEEDED.
VOLUME INCREASE(CU FT)= 4.000
NEW TOT VOL (CU FT) = 12.00
NEW TOT AREA (SQ FT) = .1090E-01
NEW PRESSURE(PSIA) = 43.06
NEW GAMMA = 1.338

BEGIN VENTING OF GASES

OVERPR(PSI)	TIME(SEC)	GASES(LB)	TEMP(R)	GAMMA	NEQN
28.36	0.	.9162	1500.	1.3377	
25.52	.5174E-01	.8708	1475.	1.3409	1
22.69	.1077	.8246	1447.	1.3424	1
19.85	.16[illegible]6	.7776	1419.	1.3439	1
17.01	.2353	.7296	1388.	1.3456	1
14.18	.3090	.6806	1355.	1.3475	1
12.67	.3515	.6541	1336.	1.3488	1
9.835	.4394	.6032	1299.	1.3509	2
7.000	.5419	.5508	1258.	1.3535	2
4.164	.6696	.4967	1212.	1.3565	2
1.329	.8619	.4406	1161.	1.3601	2
.1943	1.037	.4175	1139.	1.3622	2

FIG. 7.4 OUTPUT RESULTS FOR EXAMPLE 5

```
INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1972
RDX/AL/WAX, 74/21/5

EXPLOSIVE PROPERTIES
NUMBER FOWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G     C     H     N     O    AL
  17  1.300 .029360  .163  .027  .280  .320  .210

VENTING CALCULATION

CHARGE WEIGHT(LB)        =   .2940E-01
INIT VOLUME(CU FT)       =   8.000
INIT VENT AREA(SQ FT)    =   .5450E-02
AMBIENT PRESSURE(PSIA)   =   14.70
AMBIENT TEMP(C)          =   20.00
CHAMBER PRESSURE(PSIA)   =   14.70
CHAMBER TEMP(C)          =   20.00
NOPT=  1  NV=  2

BEGIN VENTING CALCULATION

TABLE OF VOLUME AND VENT AREA CHANGES
  P(PSIA)      T(SEC)       V(CU FT)     A(SQ FT)     PAMB(PSIA)  TAMB(C) NOPTV
  0.            .1500        4.000        .5450E-02   14.70        20.00      2
  0.            .6000        4.000        .5450E-02   14.70        20.00      2


PROPERTIES OF GASES--
OXIDATION COMPLETE
TEMPERATURE, DEGREES F  =  1653.2
ENERGY RELEASE(KCAL/G)  =  3.6573
SPECIFIC HEAT RATIO     =  1.3141
GAS OVERPRESSURE(PSI)   =  45.945

BEGIN VENTING OF GASES
OVERPR(PSI)  TIME(SEC)      GASES(LB)    TEMP(R)     GAMMA NEON
   45.94     0.             .6167        2113.       1.3141
   41.35      .6936E-01     .5809        2074.       1.3155   1
   36.76      .1453         .5443        2032.       1.3167   1
   36.49      .1500         .5422        2029.       1.3169   1
TIME HAS REACHED TV( 1)=    .1500

FAILURE LEVEL IN TABLE EXCEEDED.
VOLUME INCREASE(CU FT)=     4.000
NEW TOT VOL (CU FT)     =   12.00
NEW TOT AREA (SQ FT)    =   .1090E-01
NEW PRESSURE(PSIA)      =   36.75
NEW GAMMA               =   1.343
   22.05      .1500         .8417        1400.       1.3430   1
   19.85      .1984         .8039        1378.       1.3464   1
   17.64      .2504         .7654        1355.       1.3478   1
   15.44      .3066         .7264        1330.       1.3492   1
   13.23      .3674         .6866        1304.       1.3508   1
   12.69      .3831         .6760        1298.       1.3513   1
   10.49      .4512         .6361        1270.       1.3530   2
   8.283      .5273         .5945        1240.       1.3550   2
   6.428      .6000         .5587        1212.       1.3570   2
TIME HAS REACHED TV( 2)=    .6000

FAILURE LEVEL IN TABLE EXCEEDED.
VOLUME INCREASE(CU FT)=     4.000
NEW TOT VOL (CU FT)     =   16.00
NEW TOT AREA (SQ FT)    =   .1635E-01
NEW PRESSURE(PSIA)      =   17.06
NEW GAMMA               =   1.386
   2.358      .6000         .8582        848.7       1.3864   2
   2.122      .6170         .8496        845.4       1.3880   2
   1.886      .6351         .8410        842.1       1.3883   2
   1.651      .6543         .8324        838.7       1.3885   2
   1.415      .6750         .8237        835.3       1.3888   2
   1.179      .6976         .8151        831.9       1.3891   2
   .9431      .7226         .8063        828.4       1.3894   2
   .7074      .7511         .7976        824.9       1.3897   2
   .4716      .7850         .7888        821.3       1.3900   2
   .2358      .8296         .7799        817.7       1.3903   2
   .2358E-01  .9084         .7719        814.4       1.3906   2
```

FIG. 7.5 OUTPUT RESULTS FOR EXAMPLE 6

```
INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1972
RDX/AL/WAX, 74/21/5

EXPLOSIVE PROPERTIES
NUMBER FOWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
             KCAL/G      C      H      N      O      AL
  17  1.300 .029360   .163   .027   .280   .320   .210

VENTING CALCULATION

CHARGE WEIGHT(LB)        =   .2940E-01
INIT VOLUME(CU FT)       =   8.000
INIT VENT AREA(SQ FT)    =   .5450E-02
AMBIENT PRESSURE(PSIA)   =   14.70
AMBIENT TEMP(C)          =   20.00
CHAMBER PRESSURE(PSIA)   =   14.70
CHAMBER TEMP(C)          =   20.00
NOPT=  1  NV=  3

BEGIN VENTING CALCULATION

TABLE OF VOLUME AND VENT AREA CHANGES
  P(PSIA)     T(SEC)      V(CU FT)     A(SQ FT)     PAMB(PSIA)   TAMB(C) NOPTV
   45.00      .1500       4.000        .5450E-02    14.70        20.00     3
   20.00      .6000       4.000        .5450E-02    14.70        20.00     3
   19.00      .8000       4.000       0.            14.70        20.00     3


PROPERTIES OF GASES--
OXIDATION COMPLETE
TEMPERATURE, DEGREES F  =  1053.2
ENERGY RELEASE(KCAL/G)  =  3.6573
SPECIFIC HEAT RATIO     =  1.3141
GAS OVERPRESSURE(PSI)   =  45.945

BEGIN VENTING OF GASES
OVERPR(PSI)  TIME(SEC)      GASES(LB)   TEMP(R)    GAMMA NEON
   45.94      0.             .6167       2113.      1.3141
   41.35      .6936E-01      .5809       2074.      1.3155   1
   36.76      .1453          .5443       2032.      1.3167   1
   36.49      .1500          .5422       2029.      1.3169   1
TIME HAS REACHED TV( 1)=     .1500

FAILURE LEVEL IN TABLE EXCEEDED.
VOLUME INCREASE(CU FT)=   4.000
NEW TOT VOL (CU FT)    =   12.00
NEW TOT AREA (SQ FT)   =   .1090E-01
NEW PRESSURE(PSIA)     =   36.75
NEW GAMMA              =   1.343
   22.05      .1500          .8417       1400.      1.3430   1
   19.85      .1984          .8039       1378.      1.3464   1
   17.64      .2504          .7654       1355.      1.3478   1
   15.44      .3066          .7264       1330.      1.3492   1
   13.23      .3674          .6866       1304.      1.3508   1
   12.69      .3831          .6768       1298.      1.3513   1
   10.49      .4512          .6361       1270.      1.3530   2
   8.283      .5273          .5945       1240.      1.3550   2
   6.428      .6000          .5587       1212.      1.3570   2
TIME HAS REACHED TV( 2)=     .6000

FAILURE LEVEL IN TABLE EXCEEDED.
VOLUME INCREASE(CU FT)=   4.000
NEW TOT VOL (CU FT)    =   16.00
NEW TOT AREA (SQ FT)   =   .1635E-01
NEW PRESSURE(PSIA)     =   17.06
NEW GAMMA              =   1.386
   2.358      .6000          .8582       848.7      1.3864   2
   2.172      .6170          .8496       845.4      1.3880   2
   1.886      .6351          .8410       842.1      1.3883   2
   1.651      .6543          .8324       838.7      1.3885   2
   1.415      .6750          .8237       835.3      1.3888   2
   1.179      .6976          .8151       831.9      1.3891   2
   .9431      .7226          .8063       828.4      1.3894   2
   .7074      .7511          .7976       824.9      1.3897   2
   .4716      .7850          .7888       821.3      1.3900   2
   .2358      .8296          .7799       817.7      1.3903   2
   .2358E-01  .9084          .7719       814.4      1.3906   2
```

FIG. 7.6 OUTPUT RESULTS FOR EXAMPLE 7

```
INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1972

EXPLOSIVE PRCPERTIES
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G      C      H      N      O      AL
  17  1.300 .029360  .163  .027  .280  .320  .210
CHARGE SHAPE CORRECTION IS CRUDE.  PSI EXCEEDS
RANGE OF EXPERIMENTAL DATA.
CASE WEIGHT CORRECTION IS CRUDE.  PSI EXCEEDS
RANGE OF EXPERIMENTAL DATA.

SHOCK WAVE CALCULATION

INPUT PARAMETERS                              CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)      =   .2940E-01          ADJUSTED WT(LB TNT)    =   .6318E-01
EXPLOSIVE NUMBER       =    17                HE ENERGY FACTOR       =   1.300
L/D RATIO              =   2.700              CHARGE SHAPE FACTOR    =   2.894
CASE/CHARGE WT RATIO   =   4.240              CASE WEIGHT FACTOR     =   .5711
CHAMBER PRESSURE(PSIA)=    14.70              PRESSURE SCALE FACTOR=     .9997
CHAMBER TEMP(C)        =   20.00              DISTANCE SCALE FACTOR=     2.511
ALTITUDE (KFT)         =  0.                  TIME SCALE FACTOR      =   2.489
                                              NORMAL REFL FACTOR     =   6.752

DESIRED DISTANCE(FT)   =    .6670
                 (CM)  =    20.33

 TIME AFTER    TIME AFTER    INCIDENT     NORM REFL
 EXPLOSION     SHOCK ARR     OVERPRESS    OVERPRESS
  (MSEC)        (MSEC)         (PSI)        (PSI)
 7.1180E-02   0.              317.6        2144.
 9.5353E-02   2.4173E-02      100.2        676.2
   .1074      3.6259E-02      63.11        426.1
   .1195      4.8345E-02      40.98        276.7
   .1316      6.0431E-02      26.81        181.0
   .1437      7.2518E-02      17.27        116.6
   .1558      8.4604E-02      10.64        71.84
   .1679      9.6690E-02      5.914        39.93
   .1800       .1088          2.494        16.84
   .1920       .1209         0.           0.

IMPULSE (PSI,MSEC)--
    INCIDENT =   7.675
    REFLECTED=   51.82

CAUTION--CONTACT SURFACE HAS ARRIVED.
   DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL=  2.7874E-02
```

FIG. 7.7 OUTPUT RESULTS FOR EXAMPLE 8

INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1972

EXPLOSIVE PROPERTIES

NUMBER	EGWT	EFORM KCAL/G	C	H	N	O	AL
17	1.300	.029360	.163	.027	.280	.320	.210

(The columns C, H, N, O and AL are headed EXPLOSIVE COMPOSITION BY WEIGHT.)

CHARGE SHAPE CORRECTION IS CRUDE. PSI EXCEEDS
RANGE OF EXPERIMENTAL DATA.
CASE WEIGHT CORRECTION IS CRUDE. PSI EXCEEDS
RANGE OF EXPERIMENTAL DATA.

SHOCK WAVE CALCULATION

INPUT PARAMETERS			CHARGE WEIGHT ADJUSTMENTS		
CHARGE WEIGHT(LB)	=	.2940E-01	ADJUSTED WT(LB TNT)	=	.7408E-01
EXPLOSIVE NUMBER	=	17	HE ENERGY FACTOR	=	1.300
L/D RATIO	=	2.700	CHARGE SHAPE FACTOR	=	3.394
CASE/CHARGE WT RATIO	=	4.240	CASE WEIGHT FACTOR	=	.5711
CHAMBER PRESSURE(PSIA)	=	6.760	PRESSURE SCALE FACTOR	=	2.174
CHAMBER TEMP(C)	=	-24.60	DISTANCE SCALE FACTOR	=	1.638
ALTITUDE (KFT)	=	0.	TIME SCALE FACTOR	=	1.707
			NORMAL REFL FACTOR	=	7.852

DESIRED DISTANCE(FT) = .6670
(CM) = 20.33

TIME AFTER EXPLOSION (MSEC)	TIME AFTER SHOCK ARR (MSEC)	INCIDENT OVERPRESS (PSI)	NORM REFL OVERPRESS (PSI)
5.8490E-02	0.	276.5	21[illegible]
8.5063E-02	2.6573E-02	67.19	664.7
9.8349E-02	3.9859E-02	54.94	431.4
.1116	5.3146E-02	35.08	280.1
.1249	6.6432E-02	23.34	183.2
.1382	7.9719E-02	15.04	118.1
.1515	9.3005E-02	9.264	72.74
.1648	.1063	5.148	40.42
.1781	.1196	2.171	17.05
.1914	.1329	0.	0.

IMPULSE (PSI.MSEC)--
INCIDENT = 7.345
REFLECTED= 57.67

CAUTION--CONTACT SURFACE HAS ARRIVED.
DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 1.5305E-02

FIG. 7.8 OUTPUT RESULTS FOR EXAMPLE 9

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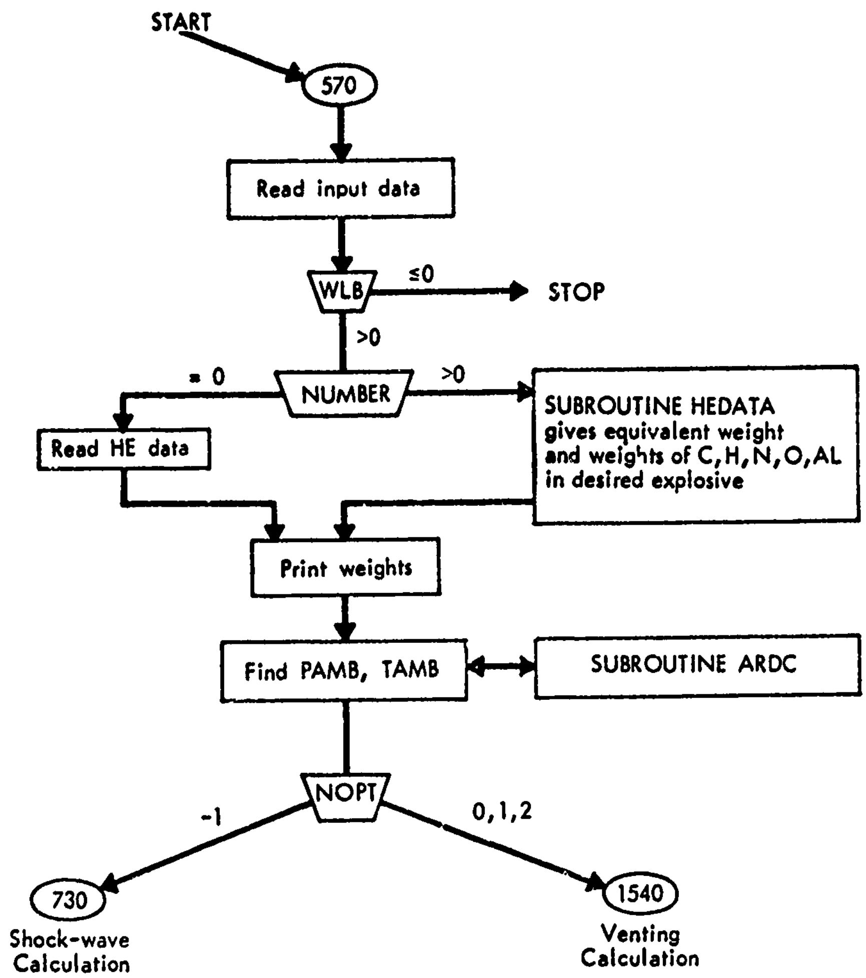
APPENDIX A

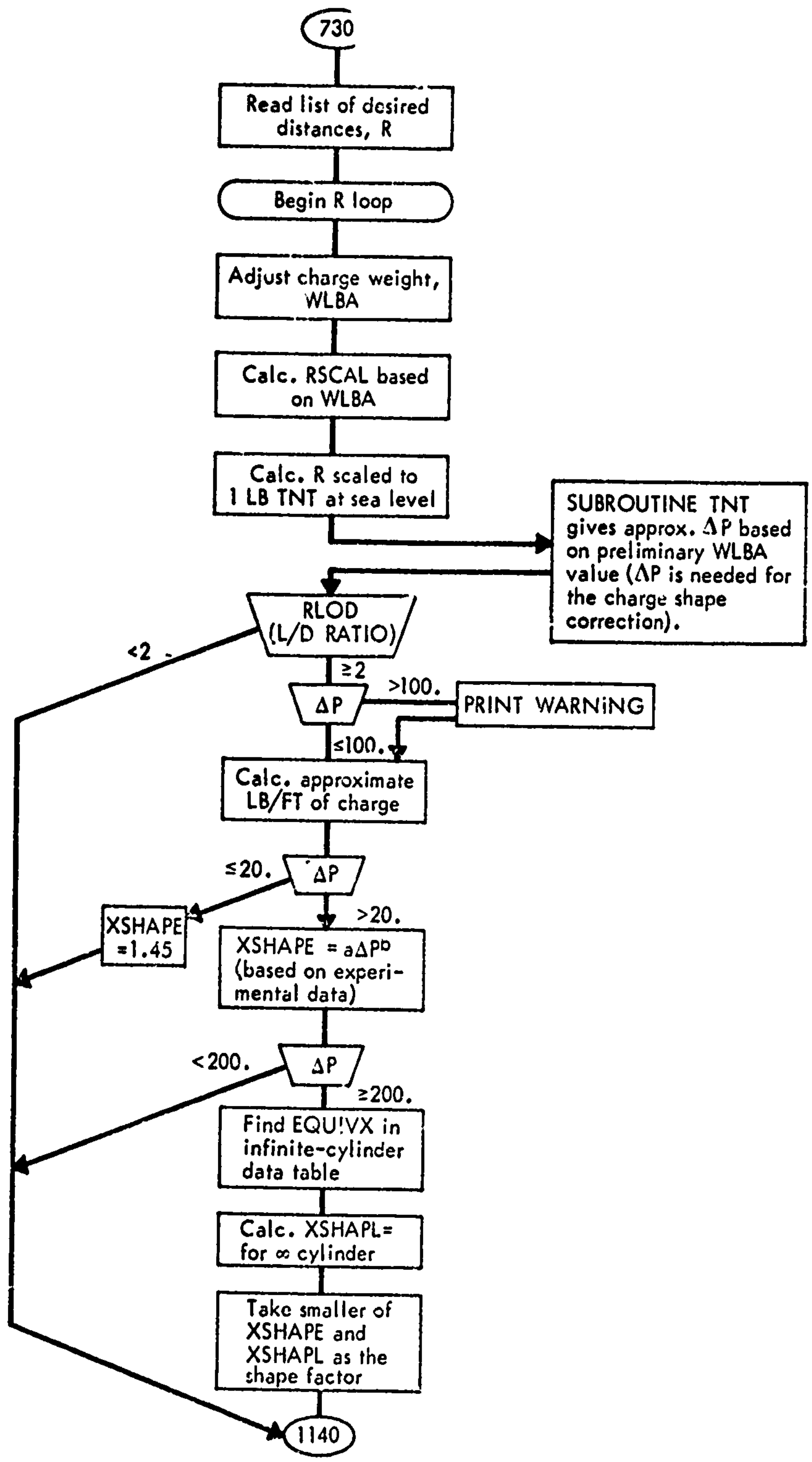
FLOW CHART FOR COMPUTER CODE

The following pages of this appendix give the complete flow chart for the computer program. It is broken into three logical sections, input, shock wave calculations, and venting calculations.

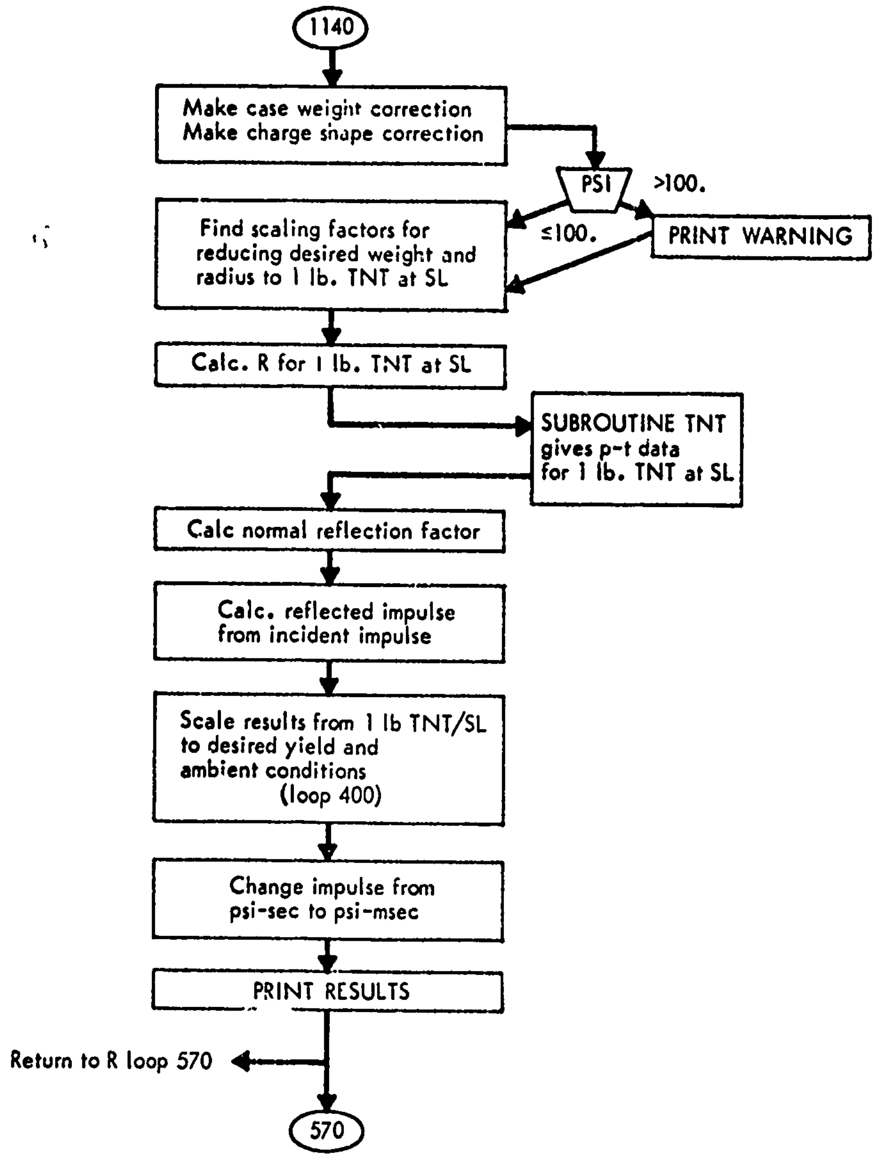
INPUT


START
570
Read input data
WLB
≤0
STOP
>0
= 0
NUMBER
>0
SUBROUTINE HEDATA
gives equivalent weight
and weights of C,H,N,O,AL
in desired explosive
Read HE data
Print weights
Find PAMB, TAMB
SUBROUTINE ARDC
NOPT
-1
0,1,2
730
Shock-wave
Calculation
1540
Venting
Calculation

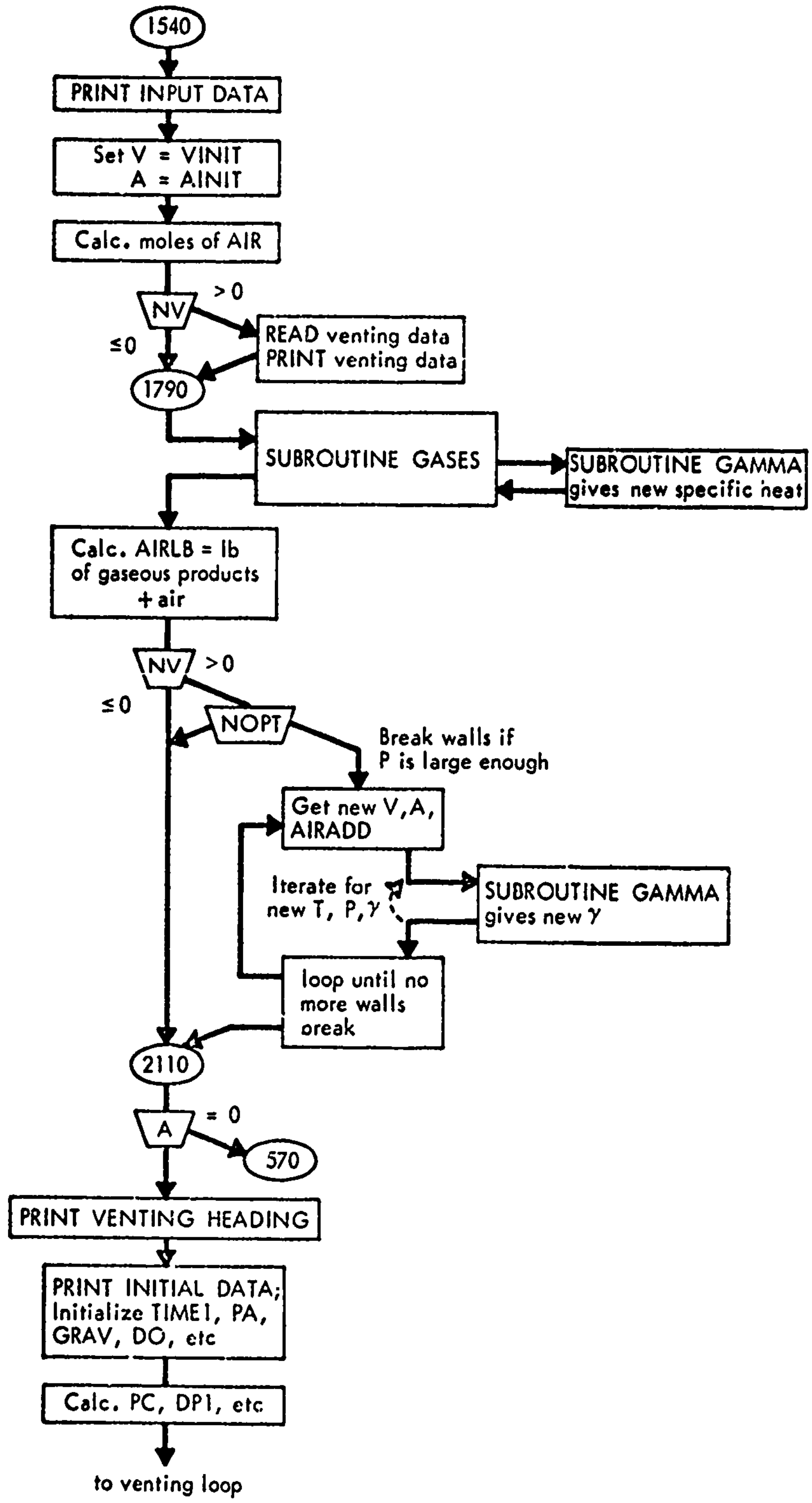
SHOCK-WAVE CALCULATION



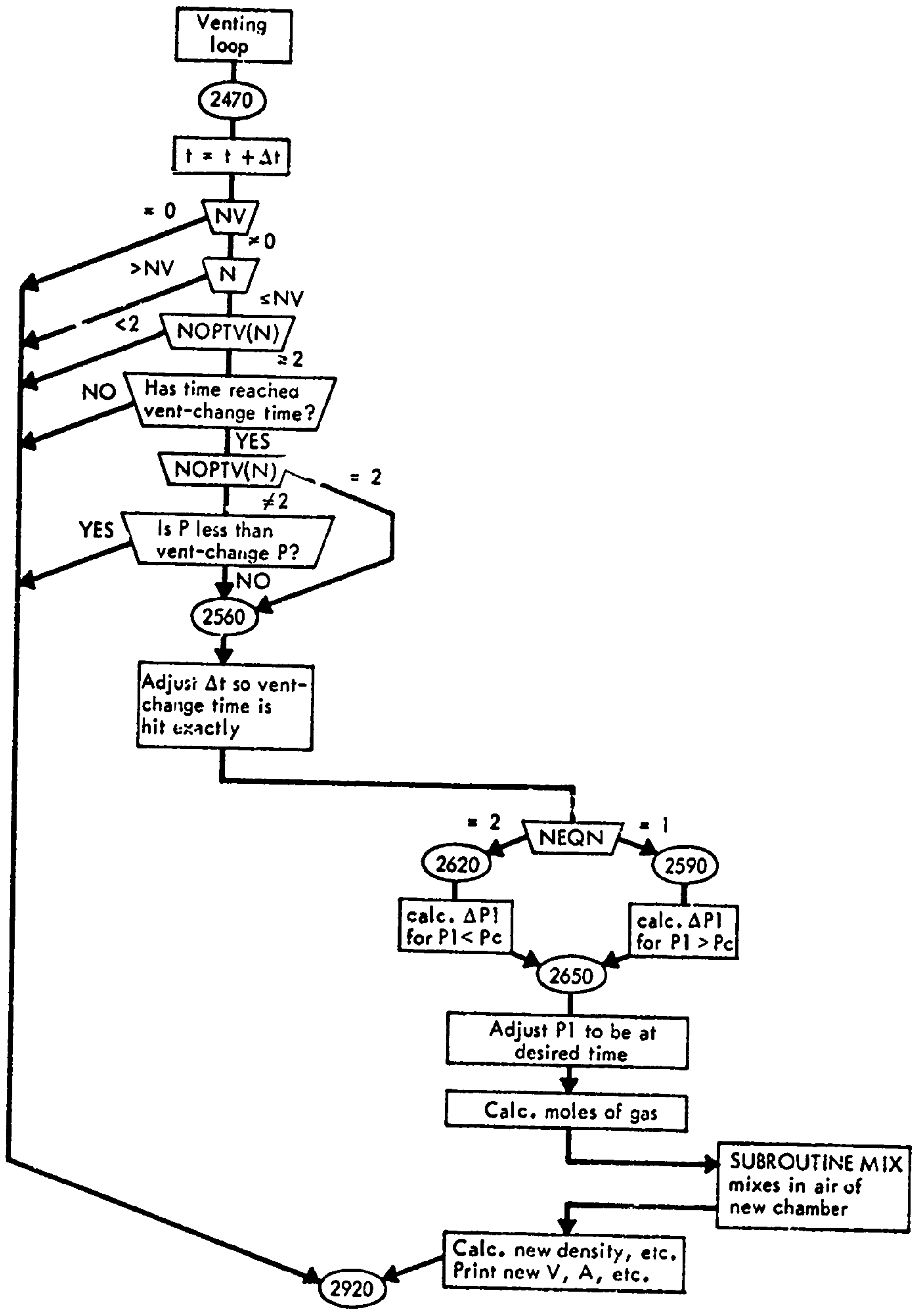
SHOCK-WAVE CALCULATION (CONT'D)



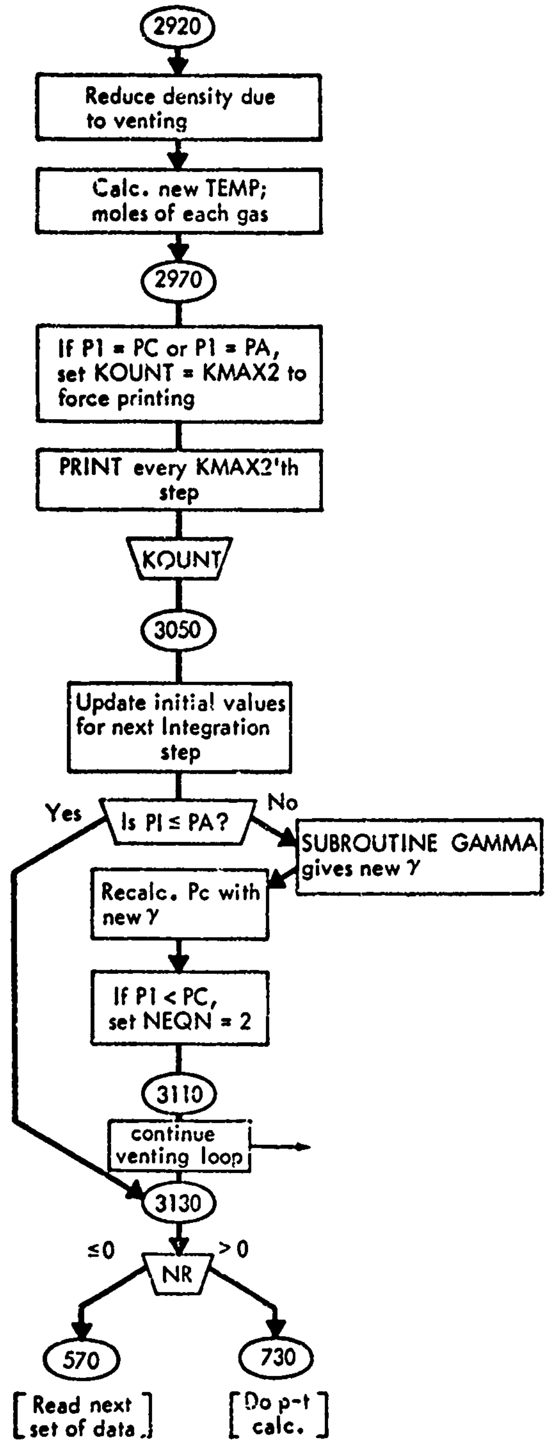
VENTING CALCULATION



VENTING CALCULATION (CONT'D)



VENTING CALCULATION (CONT'D)



APPENDIX B

INPUT DATA CARDS

This appendix provides descriptions and explanations of all of the information required on the input data cards for this program. Formats of these cards are given, and the sample problem input cards in Figure 7.1 can be used as guides.

DESCRIPTION OF INPUT DATA CARDS

```
FIRST DATA CARD--FORMAT(E5.2, I5, 9E5.2, 3I5)
   NOTE THAT THE THREE QUANTITIES INDICATED BY --*-- MAY CAUSE ADDITIONAL
   CARDS TO BE READ IN.
      WLB    =WEIGHT OF EXPLOSIVE CHARGE (POUNDS).
     *NUMBER=IDENTIFICATION NUMBER OF DESIRED EXPLOSIVE IN LIST.
           IF THE DESIRED EXPLOSIVE IS NOT IN THE LIST, EITHER
               (1) USE THE NEAREST AVAILABLE ONE IN THE LIST, OR
               (2) ADD THE NEW EXPLOSIVE TO THE LIST, OR
               (3) READ IN THE DESIRED PROPERTIES AFTER THIS CARD.
      RLOD   =LENGTH/DIAMETER RATIO.
      CASE   =CASE WEIGHT/EXPLOSIVE WEIGHT RATIO.
      VINIT  =INITIAL VOLUME OF CHAMBER (CUBIC FEET).
      AINIT  =INITIAL VENT AREA (SQUARE FEET).
      PAMB   =AMBIENT PRESSURE INTO WHICH VENTING OCCURS (PSIA).
      TAMB   =AMBIENT TEMPERATURE INTO WHICH VENTING OCCURS (CENTIGRADE).
      ALTKFT=ALTITUDE (KILOFEET).
           IF PAMB AND TAMB ARE BOTH GIVEN AS 0., THE CORRECT VALUES WILL BE
           FOUND BY THE PROGRAM FROM THE ARDC ATMOSPHERE.
           ALTKFT IS IGNORED IF PAMB AND TAMB ARE NOT 0.
      PCHAM  =INITIAL AMBIENT PRESSURE IN CHAMBER (PSIA).
      TCHAM  =INITIAL AMBIENT TEMPERATURE IN CHAMBER (C).
           IF PCHAM AND TCHAM ARE 0., THEY ARE ASSUMED TO EQUAL PAMB AND TAMB.
      NOPT   =1 DO VENTING CALC.  =2 DO SHOCK P-T CALC.
     *NV     =NUMBER OF CARDS OF VENTING CHANGE DATA TO BE READ IN.
     *NR     =NUMBER OF RADII AT WHICH SHOCK P-T DATA ARE WANTED.


SECOND DATA CARD.  OMIT THIS CARD IF NUMBER IS POSITIVE.
   THIS CARD HAS TWO POSSIBLE FORMS DEPENDING ON WHETHER NUMBER IS 0 OR -1.

   IF NUMBER=0, READ IN THE FOLLOWING EXPLOSIVE DATA FOR AN EXPLOSIVE
   NOT APPEARING IN THE LIST IN SUBROUTINE HEDATA.  FORMAT(7E7.2)
      WFACT =BLAST EQUIVALENCE RELATIVE TO TNT (USUALLY ABOUT 1.0).
      EFORM =ENERGY OF FORMATION OF THE EXPLOSIVE (CAL/GRAM).
      WFC   =WEIGHT FRACTION CARBON.
      WFH   =WEIGHT FRACTION HYDROGEN.
      WFN   =WEIGHT FRACTION NITROGEN.
      WFO   =WEIGHT FRACTION OXYGEN.
      WFA   =WEIGHT FRACTION ALUMINUM.
           (NOTE THAT THESE ARE WEIGHT FRACTION, NOT WEIGHT PERCENT.)

   IF NUMBER=-1, READ IN THE FOLLOWING DATA FOR PREPARING A MIXTURE
   OF THE COMPONENTS IN THE LIST IN SUBROUTINE HEDATA. FORMAT(E7.2,9(I3,F4.3)).
      WFACT =BLAST EQUIVALENCE RELATIVE TO TNT (USUALLY ABOUT 1.0).
      NUMHE (1)=EXPLOSIVE NUMBER IN THE TABLES.
      HEFRAC(1)=WEIGHT FRACTION OF THIS EXPLOSIVE.
      NUMHE (2)=SAME FOR SECOND COMPONENT.
      HEFRAC(2)=SAME FOR SECOND COMPONENT.
      ...       CONTINUE FOR AS MANY AS 9 COMPONENTS.
```

```
THIRD DATA CARD(S). OMIT IF NV=0.   FORMAT(6E7.2,I7)
   THERE IS ONE CARD PER N, THERE ARE NV OF THESE CARDS.
   THIS IS AN ARRAY OF VENT AREA AND VOLUME CHANGES.
      PV(N) =PRESSURE AT WHICH A-V CHANGE IS TO OCCUR (PSIA).  IF THE INITIAL
          CHAMBER PRESSURE EXCEEDS PV(N), A NEW CHAMBER IS ADDED.
      TV(N) =TIME AT WHICH A-V CHANGE IS TO OCCUR (SEC).
      VV(N) =NEW VOLUME TO BE ADDED (CUBIC FEET).
      AV(N) =NEW VENT AREA TO BE ADDED (SQUARE FEET).
      PAV(N)=AMBIENT PRESSURE IN NEW VOLUME (PSIA).
      TAV(N)=AMBIENT TEMPERATURE IN NEW VOLUME (C).
      NOPTV(N)=CONTROLS USE OF VENT AREA AND VOLUME CHANGE TABLES.
          =1 BREAK INTO NEW VOLUME IF INITIAL PRESSURE EXCEEDS PV(N).
          =2 BREAK INTO NEW VOLUME IF TIME TV(N) IS REACHED.
          =3 BREAK INTO NEW VOLUME IF PRESSURE EXCEEDS PV(N) WHEN TIME
             TV(N) IS REACHED.

FOURTH DATA CARD(S). OMIT IF NR=0.  FORMAT (10E7.2)
   THERE ARE NR/10 OF THESE CARDS WITH 10 R VALUES PER CARD.
   TOTAL OF NR ELEMENTS IN ARRAY.
      R(I)  =ARRAY OF DESIRED RADII AT WHICH SHOCK P-T DATA IS WANTED (FT).
```

APPENDIX C

DEFINITIONS OF PROGRAM VARIABLES

A complete alphabetical listing of all program variables used in this code is given in this appendix. Also a definition accompanies each listed variable.

DEFINITIONS OF PROGRAM VARIABLES

```
A      =CURRENT VALUE OF VENT AREA(SQ FT).
AINIT  =INITIAL VENT AREA(SQ FT).
AIRADD=LB MOLES OF AIR IN NEWLY ADDED CHAMBER.
AIRMOL=LB MOLES OF AIR IN ALL ACTIVE CHAMBERS.
ALTKFT=ALTITUDE(KILOFEET).  NOT USED IF PAMB, TAMB ARE GIVEN.
AV(N)  =ARRAY OF NEW VENT AREAS(SQ FT).
ALTH   =GEOPOTENTIAL ALTITUDE(METERS).
ALTZ   =ALTITUDE(METERS) ABOVE MEAN SEA LEVEL.
CASE   =CASE WEIGHT/CHARGE WEIGHT RATIO.
DIF1   =PREVIOUS DIFFERENCE BETWEEN 2 WAYS TO CALC P.
DIF2   =CURRENT  DIFFERENCE BETWEEN 2 WAYS TO CALC P.
DP1    =INTEGRATION INTERVAL IN PRESSURE(PSF).
DQ     =ENERGY ADDED(KCAL) IN INTEGRATION STEP.
DT     =INTEGRATION INTERVAL IN FINDING TEMPERATURE.
DTEMP =TEMPERATURE(R) INTERVAL IN T,P,G ITERATION.
DTIME1=TIME INTERVAL IN VENTING INTEGRATION (SEC).
DUM    =DUMMY VARIABLE IN SUBROUTINE CALL.
D0     =DENSITY(LB/CU FT) AT START OF VENTING STEP.
D1     =DENSITY(LB/CU FT) AT END OF VENTING STEP.
EF     =ARRAY OF HE ENERGY OF FORMATION DATA (CAL/G).
EFORM =ENERGY OF FORMATION OF DESIRED EXPLOSIVE (KCAL/G).
EQUIVX=INTERMEDIATE QUANTITY IN CHARGE SHAPE CORRECTION.
EQUIV2=ARRAY OF CYL-SPH EQUIVALENCE FACTORS.
EQWT   =EQUIVALENT WEIGHT REFERRED TO TNT (FOR SHOCK CALCS).
FA     =ARRAY OF WEIGHT FRACTION AL.
FC     =ARRAY OF WEIGHT FRACTION C.
FH     =ARRAY OF WEIGHT FRACTION H.
FN     =ARRAY OF WEIGHT FRACTION N.
FO     =ARRAY OF WEIGHT FRACTION O.
FLEFT =LOSS FRACTION FOR VENTING MASS CHANGES.
FRAC   =INTERPOLATION FACTOR.
G      =CURRENT VALUE OF SPECIFIC HEAT RATIO.
GASLB =POUNDS OF GAS REMAINING IN ACTIVE CHAMBERS.
GASMOL=LB MOLES OF GAS REMAINING IN ACTIVE CHAMBERS.
GG     =(G-1.)/G
GRAV   =ACCELERATION OF GRAVITY =32.2 FT/SEC/SEC.
G0     =SPECIFIC HEAT RATIO AT START OF INTEGRATION STEP.
G1     =SPECIFIC HEAT RATIO AFTER MIXING GASES.
G2     =SPECIFIC HEAT RATIO.
HEFRAC=ARRAY OF WEIGHT FRACTIONS (USED WITH NUMHE).
HF     =ABBREVIATION FOR HEFRAC(I).
I      =GENERAL DO-LOOP INDEX.
IR     =INDEX FOR DO-LOOP ON R(IR).  RANGE IS 1 TO NR.
J      =DO-LOOP INDEX
JJ     =DESIRED TNT DATA LIE BETWEEN R(JJ) AND R(JJ-1).
K      =DO-LOOP INDEX
```

```
KMAX1 =DESIRED NUMBER OF P-T POINTS BEFORE HE GASES ARRIVE.
        TYPICAL VALUES ARE 10 TO 40.
KMAX2 =VENTING PRINTOUT CONTROL. PRINT ABOUT 100/KMAX2 LINES OF
        DATA.  TYPICAL VALUES ARE 2 TO 10.
KOUNT =COUNTER FOR PRINTING DURING VENTING.
L      =DO-LOOP INDEX
MCO    =LB MOLES OF CO  IN THE CHAMBER.
MCO2   =LB MOLES OF CO2 IN THE CHAMBER.
MH2    =LB MOLES OF H2  IN THE CHAMBER.
MH2O   =LB MOLES OF H2O IN THE CHAMBER.
MN2    =LB MOLES OF N2  IN THE CHAMBER.
MO2    =LB MOLES OF O2  IN THE CHAMBER.
M1     =GRAM MOLES OF CO2 FORMED.
M2     =GRAM MOLES OF H2  FORMED.
M3     =NOT USED.
M4     =NOT USED.
M5     =GRAM MOLES OF AL2O3 FORMED.
M6     =NOT USED.
M7     =NOT USED.
M8     =GRAM MOLES OF H2O FORMED.
M9     =GRAM MOLES OF CO FORMED.
NAME   =ARRAY FOR NAMES OF EXPLOSIVES.
NAMES =ARRAY FOR NAME OF DESIRED EXPLOSIVE.
N      =EXPLOSIVE NUMBER IN TABLE, OR CHAMBER BREAKING INDEX.
NN     =INDEX FOR VENTING LOOP.
NEQN   =1 FOR P.GT.PC.    =2 FOR P.LT.PC (CHOOSES VENTING EQUATION).
NOPT   =1 DO VENTING CALC.    =2 DO SHOCK P-T CALC.
NOPTV(N)=ARRAY OF WALL-BREAKING OPTIONS.
       =1 BREAK WALL IF PRESSURE EXCEEDS PV(N).
       =2 BREAK WALL WHEN TIME TV(N) IS REACHED.
       =3 BREAK WALL IF PRESSURE EXCEEDS PV(N) AT TIME TV(N).
NR     =NUMBER OF ELEMENTS IN USE IN R ARRAY (1 TO 100).
NSAVE =LAST LINE OF VENT DATA USED IN INITIAL BREAKS.
NUMBER=NUMBER OF DESIRED EXPLOSIVE IN DATA LIST.
NUMHE =ARRAY OF EXPLOSIVE NUMBERS FOR ARBITRARY MIXING UP OF HE.
NV     =NUMBER OF ELEMENTS IN VENTING ARRAY.
N1     =GRAM MOLES OF C  IN THE EXPLOSIVE.
N2     =GRAM MOLES OF H2 IN THE EXPLOSIVE.
N3     =GRAM MOLES OF N2 IN THE EXPLOSIVE.
N4     =GRAM MOLES OF O2 IN THE EXPLOSIVE.
N5     =GRAM MOLES OF AL IN THE EXPLOSIVE.
N6     =GRAM MOLES OF N2 IN THE CHAMBER AIR.
N7     =GRAM MOLES OF O2 IN THE CHAMBER AIR.
OVERP2=ARRAY OF CYL-SPH EQUIVALENCE OVERPRESSURES (PSI).
OVPSI =OVERPRESSURE(PSI) AT START OF VENTING.
OVPSI1=CURRENT OVERPRESSURE(PSI).
OVP0   =OVERPRESSURE(PSI) AT START OF VENTING STEP.
OVP1   =OVERPRESSURE(PSI) AT END OF VENTING STEP.
```

```
P(I)   =ARRAY OF INCIDENT OVERPRESSURE(PSI) FOR TNT.
PA     =INITIAL OVERPRESSURE(PSI) IN CHAMBER WITHOUT GAMMA CORR.
PAMB   =OUTSIDE AMBIENT PRESSURE(PSIA).
PAV(N)=ARRAY OF AMBIENT PRESSURES(PSIA) IN NEW CHAMBERS.
PC(JJ)=ARRAY OF CONTACT SURFACE ARRIVAL TIME(SEC) DATA FOR TNT.
PCHAM =INITIAL AIR PRESSURE(PAIA) IN ORIGINAL CHAMBER.
PCTNT =CONTACT SURFACE OVERPRESSURE(PSI) AT RTNT.
PI     =OVERPR/PEAK OVERP RATIO FROM FITTING EQUATION.
PINIT =INITIAL CHAMBER PRESSURE(PSFA) BEFORE WALLS BREAK.
PSCAL =SCALING FACTOR FOR REDUCING PRESSURES TO SEA LEVEL.
PSFAMB=OUTSIDE AMBIENT PRESSURE(PSFA).
PSFCH =CHAMBER PRESSURE(PSFA).
PSI(I)=ARRAY OF OVERPRESSURE(PSI) AT DESIRED RADIUS R AT TIME T1(I).
PSIREF(I)=REFLECTED OVERPRESSURE(PSI) CORRESP. TO PSI(I).
PTNT   =PEAK OVERPRESSURE(PSI) AT RTNT.
PTSCAL=PSCAL*TSCAL
PV(N) =ARRAY OF PRESSURES(PSIA) WALLS CAN WITHSTAND.
PO     =PRESSURE(PSFA) AT START OF VENTING STEP.
POPSI =PO IN OVERPRESSURE(PSI).
P1     =PRESSURE(PSFA) AT END OF VENTING STEP.
P1PSI =PRESSURE(PSIA) AT END OF VENTING STEP.
P2     =PRESSURE(PSFA) AFTER WALL BREAKS.
P2A    =PRESSURE FROM FIRST EQN (FOR MIXING TWO CHAMBERS).
P2B    =PRESSURE FROM SECOND EQN (FOR MIXING TWO CHAMBERS).
Q      =ENERGY(KCAL) RELEASED BY EXPLOSION.
QPERG =ENERGY RELEASED(KCAL/GRAM).
Q1     =CUMULATIVE ENERGY DURING INTEGRATION FOR TEMPERATURE.
R      =GRAM MOLES O2 LEFT IN CHAMBER (CALLED RR IN BLAST).
R(I)   =ARRAY OF DESIRED DISTANCES(FT).  NR ELEMENTS IN THIS ARRAY.
RCM    =DISTANCE R(I) CONVERTED TO CM.
REF    =OVERPRESSURE REFLECTION FACTOR.
RESULT =QUANTITIES BEING PRINTED IN SUBROUTINE GASES.
RLOD   =LENGTH/DIAMETER RATIO OF CHARGE.
RR     =(IN BLAST ONLY) GRAM MOLES OF O2 LEFT IN THE CHAMBER.
RSCAL =SCALING FACTOR FOR REDUCING RADII TO SEA LEVEL.
RTNT   =R(IP) REDUCED TO 1 LB TNT AT SEA LEVEL.
SIGMA =SHAPE PARAMETER IN FITTING EQUATION FOR P-T DATA FOR TNT.
T      =TEMPERATURE(R) IN SUBROUTINE GAMMA.
TAMB   =OUTSIDE AMBIENT TEMPERATURE(C).
TAU    =FRACTION OF POSITIVE DURATION BASED ON 65. CM CURVE SHAPE.
TAV(N)=ARRAY OF AMBIENT TEMPS(C) IN NEW CHAMBERS.
TCHAM =INITIAL TEMP(C) IN ORIGINAL CHAMBER BEFORE EXPLOSION.
TC(JJ)=ARRAY OF TIME(SEC) BETWEEN SHOCK AND CS ARRIVAL FOR TNT.
TCMSEC=TCTNT IN MSEC.
TCTNT =CONTACT SURFACE ARRIVAL TIME(SEC) AT RTNT.
TEMP   =TEMPERATURE IN ARDC SUBROUTINE.
TEMPO =GAS TEMP(R) AT START OF VENTING STEP.
TEMP1 =GAS TEMP(R) AT END OF VENTING STEP.
TEMP2 =GAS TEMP(R) AFTER NEW CHAMBER IS ADDED.
TF     =GAS TEMPERATURE(FAHRENHEIT).
```

```
TIME1 =TIME(SEC) AT END OF VENTING STOP.
TOTMOL=TOTAL POUND MOLES OF GASES IN CHAMBER.
TP(JJ)=ARRAY OF POSITIVE OVERPR DURATION(SEC) FOR TNT.
TPTNT =POSITIVE PHASE DURATION(SEC) AT RTNT.
TR    =GAS TEMP(R) IN CHAMBER.
TRCH  =AMBIENT TEMP(R) IN ORIGINAL CHAMBER BEFORE EXPLOSION.
TS(JJ)=ARRAY OFSHOCK FRONT ARRIVAL TIME(SEC) DATA FOR TNT.
TSCAL =SCALING FACTOR FOR REDUCING TIMES TO SEA LEVEL.
TSTNT =SHOCK FRONT ARRIVAL TIME(SEC) AT RTNT.
TV(N) =ARRAY OF TIMES(SEC) FOR BREAKING WALLS.
T1(I) =ARRAY OF TIME(SEC) AFTER DETONATION.
T2(I) =ARRAY OF TIME(SEC) AFTER SHOCK ARRIVAL.
U     =SPECIFIC HEAT OF GAS MIXTURE.
U1    =SPECIFIC HEAT OF CO2.
U2    =SPECIFIC HEAT OF H2.
U4    =SPECIFIC HEAT OF O2.
U6    =SPECIFIC HEAT OF N2.
U8    =SPECIFIC HEAT OF H2O.
U9    =SPECIFIC HEAT OF CO.
V     =ACTIVE VOLUME(CU FT).
VINIT =INITIAL CHAMBER VOLUME(CU FT).
VV(N) =ARRAY OF NEW CHAMBER VOLUMES(CU FT).
V0    =CHAMBER VOLUME(CU FT) AT START OF VENTING STEP.
V1    =CHAMBER VOLUME(CU FT) AT END OF VENTING STEP.
V2    =CHAMBER VOLUME(CU FT) AFTER NEW CHAMBER IS ADDED.
WA    =POUNDS OF AL IN THE EXPLOSIVE.
WC    =POUNDS OF C IN THE EXPLOSIVE.
WFA   =WEIGHT FRACTION OF AL IN THE EXPLOSIVE.
WFACT =CHARGE ENERGY RELATIVE TO EQUAL WEIGHT OF TNT.
WFC   =WEIGHT FRACTION OF C IN THE EXPLOSIVE.
WFH   =WEIGHT FRACTION OF H IN THE EXPLOSIVE.
WFN   =WEIGHT FRACTION OF N IN THE EXPLOSIVE.
WFO   =WEIGHT FRACTION OF O IN THE EXPLOSIVE.
WFT   =APPROXIMATE CHARGE LENGTH(FT).
WH    =POUNDS OF H IN THE EXPLOSIVE.
WLB   =WEIGHT(LB) OF EXPLOSIVE CHARGE.
WLBA  =ADJUSTED CHARGE WEIGHT(LB).
WN    =POUNDS OF N IN THE EXPLOSIVE.
WO    =POUNDS OF O IN THE EXPLOSIVE.
WPERL =APPROXIMATE CHARGE WEIGHT PER UNIT LENGTH(LB/FT).
XCASE =CORRECTION FACTOR FOR CASE EFFECT.
XIMP1 =SIDE-ON POSITIVE IMPULSE BEFORE HE GAS ARRIVAL (PSI.MSEC).
XIMP1R=REFLECTED OVERPR POSITIVE IMPULSE BEFORE GAS ARR (PSI.MSEC).
XSHAPE=CORRECTION FACTOR FOR CHARGE CYLINDRICITY.
XSHAPL=CORRECTION FACTOR FOR INFINITE LINE CHARGE.
X2    =GRAM MOLES OF GAS IN IN CHAMBER.
X3    =GRAM MOLES OF GAS IN CHAMBER WITHOUT THE AIR.
```

APPENDIX D

FORTRAN LISTING OF PROGRAM

This appendix gives the complete FORTRAN listing of the computer program. All seven sections are labeled with appropriate card numbers.

BLAS0010 - BLAS3160
MIX 0010 - MIX 0270
HEDA0010 - HEDA1400
GAMM0010 - GAMM0160
GAS 0010 - GAS 0890
TNT 0010 - TNT 1330
ARDC0010 - ARDC0410

FORTRAN LISTING OF PROGRAM

```
      PROGRAM BLAST(INPUT,OUTPUT)
      COMMON/DATA1/WLB,NUM,LR,RLOD,CASE,VINIT,AINIT,PAMB,TAMB,ALTKFT,
     1 PCHAM,TCHAM,NOPT,V,AR,WFACT,LFORM
      COMMON/TNTIN/RTNT,WMAX1
      COMMON/TNTOUT/PTNT,TSTNT,IPTNT,ICTNT,PCTNT,PSI(40),T1(40),T2(40)
     1,JJ,XIMP1
      COMMON/MOLGAS/MO2,MN2,MCO,MCO2,MH2O,MH2
      COMMON/HEMASS/WC,WH,WN,WO,WA
      COMMON/XTERAC/WFC,WFH,WFN,WFO, FA
      COMMON/GAS/N1,N2,N3,N4,N5,N6,N7,
     1 M1,M2,M3,M4,M5,M6,M7,M8,M9, RR,Q,X2
      COMMON/VENT/ PV(10),TV(10),VV(10),AV(10),PAV(10),TAV(10),NOPTV(10)
     1,N
      COMMON/HE/NUMHE(9),HEFRAC(9)
      DIMENSION PSIREF(40),R(100)
C
      DIMENSION OVERP2(24),EQUIV2(24)
      REAL M2,M6,M8
      REAL MO2,MN2,MCO,MCO2,MH2O,MH2
C
C TABLES FOR CYLINDRICAL VS SPHERICAL CHARGE EQUIVALENCE.
      DATA EQUIV2/5.12,4.90,4.00,3.50,3.16,2.59,2.40,2.17,1.93,1.71,
     1 1.53,1.35,1.20,1.05,.80,.45,.24,.158,.085,.057,
     2 .042,.040,.032,.032/
      DATA OVERP2/200.,300.,400.,500.,600.,700.,800.,900.,1000.,1100.,
     1 1200.,1300.,1400.,1500.,1700.,2000.,2500.,3000.,4000.,5000.,
     2 6000.,6500.,7000.,1.E6/
C
  300 FORMAT(E5.2,I5,9E5.2,3I5)
  305 FORMAT(L7.0,9(I3,F4.3))
  310 FORMAT(10E7.0)
  320 FORMAT(*0SHOCK WAVE CALCULATION*/
     1*0INPUT PARAMETERS          *,16X,   *CHARGE WEIGHT ADJUSTMENTS*/
     2* CHARGE WEIGHT(LB)       =*G12.4,4X,*ADJUSTED WT(LB TNT)   =*G12.4/
     3* EXPLOSIVE NUMBER        =*I6,10X,  *HE ENERGY FACTOR      =*G12.4/
     4* L/D RATIO               =*G12.4,4X,*CHARGE SHAPE FACTOR   =*G12.4/
     5* CASE/CHARGE WT RATIO    =*G12.4,4X,*CASE WEIGHT FACTOR    =*G12.4/
     6* CHAMBER PRESSURE(PSIA)=*G12.4,4X,*PRESSURE SCALE FACTOR=*G12.4/
     7* CHAMBER TEMP(C)         =*G12.4,4X,*DISTANCE SCALE FACTOR=*G12.4/
     8* ALTITUDE (KFT)          =*G12.4,4X,*TIME SCALE FACTOR     =*G12.4/
     9 36X,                            4X,*NORMAL REFL FACTOR    =*G12.4)
  420 FORMAT(*1INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1972*)
  430 FORMAT(*0DESIRED DISTANCE(FT)     =*1PG12.4/
     1*                    (CM)     =*1PG12.4)
  450 FORMAT(
     1*0 TIME AFTER   TIME AFTER    INCIDENT    NORM REFL   */
     2*  EXPLOSION    SHOCK ARR    OVERPRESS    OVERPRESS   */
     3*   (MSEC)       (MSEC)        (PSI)        (PSI)     *)
  490 FORMAT(1X,1P4G12.4)
  500 FORMAT(*0IMPULSE (PSI-MSEC)--*/
     1*     INCIDENT =*1PG12.4/*     REFLECTED=*1PG12.4)
  520 FORMAT(*0CAUTION--CONTACT SURFACE HAS ARRIVED.*/
     1*    DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL=*1PG12.4)
  535 FORMAT(* CHARGE SHAPE CORRECTION IS CRUDE.  PSI EXCEEDS */
     1        * RANGE OF EXPERIMENTAL DATA.*)
  540 FORMAT(* CASE WEIGHT CORRECTION IS CRUDE.  PSI EXCEEDS */
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      1        * RANGE OF EXPERIMENTAL DATA.*)                        BLAS0542
       KMAX1=10   $KMAX2=10                                            BLAS0560
C                                                                      BLAS0562
C READ INPUT DATA.                                                     BLAS0565
  570 READ 300,WLB,NUMBER,RLOD,CASE,VINIT,AINIT,PAMB,TAMB,ALTKFT,       BLAS0570
     1 PCHAM,TCHAM,NOPT,NV,NR                                          BLAS0572
       IF(WLB.LE.0.) STOP   $PRINT 420   $IF(NUMBER.EQ.0) GO TO 600     BLAS0574
       IF(NUMBER.NE.-1) GO TO 596                                      BLAS0576
       READ 305,WFACT,(NUMHF(I),HEFRAC(I),I=1,9)                       BLAS0580
  596 CALL HEDATA   $GO TO 605                                         BLAS0596
  600 READ 310,WFACT,EFORM,WFC,WFH,WFN,WFO,WFA   $EFORM=EFORM/1000.    BLAS0600
C POUNDS OF EACH ELEMENT                                               BLAS0602
  605 WC=WFC*WLB  $WH=WFH*WLB  $WN=WFN*WLB  $WO=WFO*WLB  $WA=WFA*WLB   BLAS0605
       IF(WFACT.GT.0.) GO TO 615                                       BLAS0608
       WFACT=1.   $PRINT 612                                           BLAS0610
  612 FORMAT(* WFACT NOT KNOWN, 1.0 IS USED.*)                         BLAS0612
  615 PRINT 620,NUMBER,WFACT,EFORM,WFC,WFH,WFN,WFO,WFA                 BLAS0615
  620 FORMAT(*0EXPLOSIVE PROPERTIES*/                                  BLAS0620
     1* NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT*/          BLAS0625
     2*               KCAL/G     C     H     N     O    AL  */         BLAS0630
     31H ,I4,F7.3,F8.4,5F6.3)                                          BLAS0640
C FIND PAMB AND TAMB IF NOT GIVEN.                                     BLAS0650
       IF(PAMB.EQ.0.) CALL ARDC(ALTKFT,PAMB,TAMB)                      BLAS0660
       IF(PCHAM.LE.0.) PCHAM=PAMB   $IF(TCHAM.LE.0.) TCHAM=TAMB        BLAS0670
C DO VENTING CALC IF NOPT=1 AND DO SHOCK WAVE CALC IF NOPT=2.          BLAS0690
       IF(NOPT.LT.2) GO TO 1540                                        BLAS0700
C                                                                      BLAS0710
C BEGIN SHOCK-WAVE PROPERTIES SECTION.                                 BLAS0720
  730 READ 310,(R(IR),IR=1,NR)                                         BLAS0730
       DO 1480 IR=1,NR    $IF(IR.EQ.1) GO TO 760                       BLAS0740
       PRINT 420   $PRINT 620,NUMBER,WFACT,EFORM,WFC,WFH,WFN,WFO,WFA   BLAS0750
  760 RCM=R(IR)*30.48                                                  BLAS0760
C ADJUST CHARGE WEIGHT.                                                BLAS0770
       WLBA=WLB*WFACT   $PAMB=PCHAM   $TAMB=TCHAM                      BLAS0780
       RSCAL=(1./(WLBA*PAMB/14.696176))**.33333333                     BLAS0800
       RTNT=RCM*RSCAL   $CALL TNT(0)                                   BLAS0810
C MAKE CHARGE SHAPE CORRECTION.                                        BLAS0830
       XSHAPE=1.   $IF(RLOD.LT.2.) GO TO 1140                          BLAS0840
       IF(PSI(1).GT.100.) PRINT 535                                    BLAS0850
C CHARGE WEIGHT PER UNIT LENGTH OF CYLINDRICAL CHARGE.                 BLAS0860
       WPERL=(3.1416*100./(4.*RLOD**2))**.33333333 *WLBA**.66666666    BLAS0870
C MAKE CHARGE SHAPE CORRECTION.                                        BLAS0880
       IF(PSI(1).GT.20.) GO TO 900   $XSHAPE=1.45   $GO TO 1140        BLAS0890
  900 XSHAPE=0.613*PSI(1)**.287                                        BLAS0900
C FIND INFINITE-CYLINDER CHARGE SHAPE CORRECTION.                      BLAS0910
       IF(PSI(1).LT.200.) GO TO 1140                                   BLAS0920
       DO 940 I=2,24    $IF(PSI(1).LT.OVERP2(I)) GO TO 950             BLAS0930
  940 CONTINUE   $I=24                                                 BLAS0940
  950 FRAC=(PSI(1)-OVERP2(I-1))/(OVERP2(I)-OVERP2(I-1))                BLAS0950
       EQUIVX=EQUIV2(I-1)+FRAC*(EQUIV2(I)-EQUIV2(I-1))                 BLAS0960
       XSHAPL=EQUIVX*WPERL**1.5/WLBA                                   BLAS0970
       IF(XSHAPL.LT.XSHAPE) XSHAPL=XSHAPL                              BLAS0980
C TEST IF DESIRED DISTANCE IS CLOSE ENOUGH TO CHARGE FOR GOOD RESULTS. BLAS1010
C APPROX. CHARGE LENGTH.                                               BLAS1020
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 1030 WFT=WPERL*WLB                                                        BLAS1030
C MAKE CASE WEIGHT CORRECTION.  CASE=CASE/CHARGE WEIGHT RATIO.             BLAS1130
 1140 XCASE=0.47+0.53/(1.+CASE)                                            BLAS1140
      IF(CASE.LT.0.53) XCASE=1.-CASE**2/(1.+CASE)                          BLAS1150
      WLBA=WLBA*XSHAPE*XCASE                                               BLAS1160
      IF(PSI(1).GT.100.) PRINT 540                                         BLAS1162
C FIND SCALING FACTORS.                                                    BLAS1170
      PSCAL=14.696178/PAMB                                                 BLAS1180
      RSCAL=(1./WLBA*PAMB/14.696178)**.33333333                            BLAS1190
      TSCAL=RSCAL*SQRT((273.16+TAMB)/288.16)                               BLAS1200
C FIND DESIRED RADIUS FOR 1 LB TNT AT SEA LEVEL.                           BLAS1210
      RTNT=RCM*RSCAL                                                       BLAS1220
C FIND DATA IN TABLES.                                                     BLAS1230
      CALL TNT(1)                                                          BLAS1240
C CALCULATE NORMAL REFLECTION FACTOR.                                      BLAS1250
      IF(PSI(1).GT.200.) GO TO 1280                                        BLAS1260
      REF=(7.*14.696178+4.*PSI(1))/(7.*14.696178+PSI(1))*2.$GO TO 1290     BLAS1270
 1280 REF=-3.18+3.97*ALOG10(PSI(1))   $IF(REF.GT.13.) REF=13.              BLAS1280
 1290 XIMP1R=XIMP1*REF                                                     BLAS1290
C SCALE RESULTS TO DESIRED CHARGE WEIGHT AND AMBIENT CONDITIONS.           BLAS1300
C CHANGE TIMES FROM SECONDS TO MSEC.                                       BLAS1310
      DO 1350 K=1,KMAX1                                                    BLAS1320
      PSI(K)=PSI(K)/PSCAL   $PSIREF(K)=PSI(K)*REF                          BLAS1330
      T1(K)=T1(K)/TSCAL*1000.    $T2(K)=T2(K)/TSCAL*1000.                  BLAS1340
 1350 CONTINUE                                                             BLAS1350
      PTSCAL=PSCAL*TSCAL                                                   BLAS1355
      XIMP1=XIMP1*1000./PTSCAL   $XIMP1R=XIMP1R*1000./PTSCAL               BLAS1360
C PRINT THE RESULTS.                                                       BLAS1380
      PRINT 320,WLB,WLBA, NUMBER,WFACT, RLOD,XSHAPE, CASE,XCASE,           BLAS1390
     1 PAMB,PSCAL, TAMB,RSCAL, ALTKFT,TSCAL, REF                           BLAS1400
      PRINT 430,R(IR),RCM   $PRINT 450                                     BLAS1410
      PRINT 490,(T1(K),T2(K),PSI(K),PSIREF(K),K=1,KMAX1)                   BLAS1420
      PRINT 500,XIMP1,XIMP1R   $TCMSEC=TCTNT*1000./TSCAL                   BLAS1430
      IF(RTNT.LT.65.) PRINT 520,TCMSEC                                     BLAS1440
 1480 CONTINUE                                                             BLAS1480
      GO TO 570                                                            BLAS1490
C END SHOCK-WAVE PROPERTIES SECTION.                                       BLAS1500
C                                                                          BLAS1510
C                                                                          BLAS1520
C BEGIN VENTING SECTION.                                                   BLAS1530
 1540 PRINT 1550,WLB,VINIT,AINIT,PAMB,TAMB,PCHAM,TCHAM,NCPT,NV             BLAS1540
 1550 FORMAT(*0VENTING CALCULATION*/                                       BLAS1550
     1*0CHARGE WEIGHT(LB)      =*G12.4/                                    BLAS1560
     3* INIT VOLUME(CU FT)     =*G12.4/                                    BLAS1580
     4* INIT VENT AREA(SQ FT)  =*G12.4/                                    BLAS1590
     5* AMBIENT PRESSURE(PSIA)=*G12.4/                                     BLAS1600
     6* AMBIENT TEMP(C)        =*G12.4/                                    BLAS1610
     7* CHAMBER PRESSURE(PSIA)=*G12.4/                                     BLAS1620
     8* CHAMBER TEMP(C)        =*G12.4/                                    BLAS1630
     9* NCPT=*I3,*  NV=*I3)                                                BLAS1640
 1650 FORMAT(6E7.0,I7)                                                     BLAS1650
 1660 FORMAT(*0TABLE OF VOLUME AND VENT AREA CHANGES*/                     BLAS1660
     1*    P(PSIA)      T(SEC)       V(CU FT)     A(SQ FT)     PAMB(PSIA)  TABLAS1670
     2MB(C) NOPTV*/10(1H ,6G12.4,I2/))                                     BLAS1680
 1690 FORMAT(*0BEGIN VENTING CALCULATION*)                                 BLAS1690
```

```
C
      A=AINIT
      PRINT 1690
      PSFCH=PCHAM*144.    $TRCH=(TCHAM+273.16)*1.8    $PSFAMB=PAMB*144.
C POUND MOLES OF AIR.
      AIRMOL=PSFCH*VINIT/(1545.*TRCH)
      IF(NV.LE.0) GO TO 1790
      READ 1650,(PV(N),TV(N),VV(N),AV(N),PAV(N),TAV(N),NOPTV(N),N=1,NV)
      PRINT1660,(PV(N),TV(N),VV(N),AV(N),PAV(N),TAV(N),NOPTV(N),N=1,NV)
 1790 CALL GASES(VINIT,AIRMOL,OVPO,GO,TR)
      GASLB=32.*MO2+ 28.*MN2+ 28.*MCO+ 44.*MCO2+ 18.*MH2O+ 2.*MH2
      GASMOL=MO2+MN2+MCO+MCO2+MH2O+MH2
C PINIT=INITIAL CHAMBER PRESSURE (PSFA) AFTER EXPLOSION.
      PINIT=OVPO*144. +PSFCH
      PO=PINIT   $VO=VINIT    $TEMPO=TR    $NSAVE=1
      IF(NV.LE.0) GO TO 2110
      IF(NOPTV(1).NE.1) GO TO 2110
C
C BREAK WALLS IF PO EXCEEDS TABULATED VALUES.
      DO 2070 N=1,NV    $NSAVE=N
      IF(NOPTV(N).NE.1) GO TO 2110
      IF(PO.LT.PV(N)*144.) GO TO 2070
      A=A+AV(N)
      CALL MIX(PO,VO,TEMPO,GO,GASMOL, P2,V2,TEMP2,G2,AIRADD)
      PO=P2    $VO=V2    $TEMPO=TEMP2    $GO=G2
C PO, VO, TEMPO, GO ARE NOW AFTER NEW VOLUME IS ADDED.
C ADD NEW AIR TO MOLES OF N2 AND O2.
      MN2=MN2+.7905*AIRADD    $MO2=MO2+.2095*AIRADD
      GASMOL=MO2+MN2+MCO+MCO2+MH2O+MH2
      POPSI=PO/144.
      PRINT 2010,VV(N),V2,A,POPSI,G2
 2010 FORMAT(*0FAILURE LEVEL IN TABLE EXCEEDED.*/
     1* VOLUME INCREASE(CU FT)=*G12.4/
     2* NEW TOT VOL (CU FT)    =*G12.4/
     3* NEW TOT AREA (SQ FT)   =*G12.4/
     4* NEW PRESSURE(PSIA)     =*G12.4/
     5* NEW GAMMA              =*G12.4)
 2070 CONTINUE
C INITIAL BREAKING INTO NEW CHAMBERS IS NOW COMPLETED.
C
C NO VENTING IF AREA=0.
 2110 IF(A.EQ.0.) GO TO 570
C      PO=INITIAL PEAK PRESSURE (PSFA).
C      VO=INITIAL VOLUME (CU FT).
C      TO=INITIAL TEMP(R).
      PRINT 2160
 2160 FORMAT(*0BEGIN VENTING OF GASES*/
     1* OVERPR(PSI)   TIME(SEC)      GASES(LB)    TEMP(R)    GAMMA NEQN*)
      OVPSI=(PO-PSFAMB)/144.    $TIME1=0.    $G=GO
      GASLB=32.*MO2+ 28.*MN2+ 28.*MCO+ 44.*MCO2+ 18.*MH2O+ 2.*MH2
      PRINT 3030,OVPSI,TIME1,GASLB,TEMPO,G
      PA=PSFAMB    $GRAV=32.2
C DENSITY (LB/CU FT).
      DO=GASLB/VO
C CRITICAL PRESSURE (PSFA).
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      PC=PA/((2./(G+1.))**(G/(G-1.)))
C PRESSURE INCREMENT
      DP1=(P0-PA)*.01
      NEON=1    $TIME1=0.   $KOUNT=1
      V1=V0
C
      N=NSAVE
C BEGIN VENTING LOOP.
      DO 3110 NN=1,1000  $P1=P0-DP1   $G=G0
      IF(P1.GT.PA) GO TO 2360
      KOUNT=99   $P1=P0   $GO TO 3010
 2360 GO TO (2380,2430),NEON
C VENTING FOR P1.GT.PC
 2380 IF(P1.LE.PC.AND.P0.GT.PC) P1=PC
      DTIME1=(P0-P1)/P1**((3.*G-1.)/(2.*G))*V1/A/
     1 SQRT(GRAV*G**3*P0**(1./G)/D0*(2./(G+1.))**((G+1.)/(G-1.)))
      GO TO 2470
C VENTING FOR P1.LT.PC
 2430 IF(P1.LT.PA.AND.P0.GT.PA) P1=PA
      GG=(G-1.)/G
      DTIME1=(PC-P1)/(P1**GG*(P1**GG-PA**GG)**.5)*V1/A/
     1 SQRT(GRAV*G**3*2./(G-1.)*(PC*PA**2/D0**G)**(1./G))
 2470 TIME1=TIME1+DTIME1
      IF(NV.EQ.0) GO TO 2920
      IF(N.GT.NV) GO TO 2920
      IF(NOPTV(N).LT.2) GO TO 2920
C CHECK TIME AGAINST VENTING TABLE.
      IF(TIME1.LT.TV(N)) GO TO 2920
      IF(NOPTV(N).EQ.2) GO TO 2560
      IF(P1.LT.PV(N)*144.) GO TO 2920
C ADJUST TIME1 TO EQUAL TV.
 2560 DTIME1=TV(N)-(TIME1-DTIME1)
      TIME1=TV(N)
      GO TO (2590,2620),NEON
 2590 DP1 =P1**((3.*G-1.)/(2.*G))*A/V1*DTIME1*
     1 SQRT(GRAV*G**3*(P0**(1./G)/D0)*(2./(G+1.))**((G+1.)/(G-1.)))
      GO TO 2650
 2620 GG=(G-1.)/G
      DP1=P1**GG*(P1**GG-PA**GG)**.5*A/V1*DTIME1*
     1 SQRT(GRAV*G**3*(2./(G-1.))*(P0 *PA**2/D0**G)**(1./G))
 2650 P1=P0-DP1   $OVP1=P1-PA   $OVPSI1=OVP1/144.
C REDUCE MASSES DUE TO VENTING.
      D1=D0*(P1/P0)**(1./G)
      TEMP1=TEMP0*(P1/P0)**((G-1.)/G)
C FRACTION LEFT AFTER THIS VENTING STEP.
      FLEFT=D1/D0
      MO2=MO2*FLEFT   $MN2=MN2*FLEFT   $MCO=MCO*FLEFT
      MCO2=MCO2*FLEFT   $MH2O=MH2O*FLEFT   $MH2=MH2*FLEFT
      GASLB=D1*V1
      GASMOL=MO2+MN2+MCO+MCO2+MH2O+MH2
      PRINT 3030,OVPSI1,TIME1,GASLB,TEMP1,G,NEON
      PRINT 2770,N,TIME1
 2770 FORMAT(* TIME HAS REACHED TV(*I2*)=*G12.4)
C BEGIN VOLUME-AREA CHANGE SECTION.
      A=A+AV(N)
```

```
      CALL MIX(P1,V1,TEMP1,G,GASMOL, P2,V2,TEMP2,G2,AIRADD)
      P1=P2   $V1=V2   $TEMP1=TEMP2   $G=G1=G2
      MN2=MN2+.7905*AIRADD
      MO2=MO2+.2095*AIRADD
      GASLB=32.*MO2+ 28.*MN2+ 28.*MCO+ 44.*MCO2+ 18.*MH2O+ 2.*MH2
      V1=V2   $P1PSI=P1/144.
      D1=GASLB/V1   $OP1=(P1-PA)*.01
      PRINT 2010,VV(N),V1,A,P1PSI,G1
      N=N+1   $KOUNT=KMAX2   $GO TO 2970
C END VOLUME-AREA CHANGE SECTION.
C
C REDUCE MASSES DUE TO VENTING.
 2920 D1=D0*(P1/P0)**(1./G)
      TEMP1=TEMP0*(P1/P0)**((G-1.)/G)
      FLEFT=D1/D0   $GASLB=D1*V1
      MO2=MO2*FLEFT   $MN2=MN2*FLEFT   $MCO=MCO*FLEFT
      MCO2=MCO2*FLEFT   $MH2O=MH2O*FLEFT   $MH2=MH2*FLEFT
 2970 IF(P1.EQ.PC) KOUNT=KMAX2
      IF(P1.EQ.PA) KOUNT=KMAX2
C PRINT EVERY KMAX2-TH LINE.
      IF(KOUNT.NE.KMAX2) GO TO 3050   $KOUNT=0
 3010 OVPSI1=(P1-PA)/144.
      PRINT 3030,OVPSI1,TIME1,GASLB,TEMP1,G,NEON
 3030 FORMAT(1H ,4G12.4,F7.4,I4)
      IF(KOUNT.EQ.99) GO TO 3130
 3050 P0=P1   $KOUNT=KOUNT+1   $D0=D1   $TEMP0=TEMP1
      IF(P1.LE.PA) GO TO 3130
      CALL GAMMA(TEMP1,G0,DUM)   $G=G0
C RECALCULATE PC WITH NEW G.
      IF(P1.GT.PC) PC=PA/((2./(G+1.))**(G/(G-1.)))
      IF(P1.LE.PC) NEON=2
 3110 CONTINUE
C END VENTING LOOP.
 3130 IF(NR.GT.0) GO TO 730
      GO TO 570
C END VENTING SECTION.
      END
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```
      SUBROUTINE MIX(P0,V0,TEMP0,G0,GASMOL, P2,V2,TEMP2,G2,AIRADD)
C MIX THE GASES IN ADJACENT CHAMBERS.
      COMMON/VENT/ PV(10),TV(10),VV(10),AV(10),PAV(10),TAV(10),NOPTV(10)
     1,N
      V2=V0+VV(N)
C MOLES OF AIR IN THE NEW VOLUME.
      AIRADD=(PAV(N)*144.)*VV(N)/(1545.*(TAV(N)+273.16)*1.8)
C ITERATE TO FIND NEW T,P,G.
      TOTMOL=GASMOL+AIRADD
      DIF1=1.E10    $DTEMP=TEMP0/100.
C P0, V0, TEMP0, G0 ARE BEFORE NEW VOLUME IS ADDED.
C P2, V2, TEMP2, G2 ARE AFTER  NEW VOLUME IS ADDED.
C FIRST GUESS FOR TEMP2.
      TEMP2=TEMP0
      DO 240 J=1,100
      P2A=(TOTMOL*1545./V2)*TEMP2
      CALL GAMMA(TEMP2,G2,DUM)
      P2B=(G2-1.)/V2 *((1.4-1.)*P0*V0 +(G0-1.)*PAV(N)*VV(N))/
     1 ((1.4-1.)*(G0-1.))
      DIF2=ABS(P2A-P2B)
      IF(DIF2.GT.DIF1) GO TO 250
C CONTINUE SEARCH FOR CORRECT TEMP2.
      TEMP2=TEMP2-DTEMP   $DIF1=DIF2
  240 CONTINUE
  250 P2=(P2A+P2B)/2.
      RETURN
      END
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      SUBROUTINE HEDATA                                                 HEDA0010
C TABLES OF EXPLOSIVES DATA.                                            HEDA0020
      COMMON/DATA1/WLB,NUMBER,RLOD,CASE,VINIT,AINIT,PAMB,TAMB,ALTKFT,   HEDA0030
     1 PCHAM,TCHAM,NOPT,NV,NR, WFACT,EFORM                              HEDA0040
      COMMON/WTFRAC/WFC,WFH,WFN,WFO,WFA                                 HEDA0060
      COMMON/HE/NUMHE(9),HEFRAC(9)                                      HEDA0065
      DIMENSION EQWT(40),EF(40),FC(40),FH(40),FN(40),FO(40),FA(40)      HEDA0070
      DIMENSION NAME(40,5),NAMES(5)                                     HEDA0075
C EQWT=EQUIVALENT WEIGHT REFERRED TO TNT.                               HEDA0080
C EF=ENERGY OF FORMATION (CAL/G).                                       HEDA0090
      DATA((NAME( 1,I),I=1,5)=10H(37H TNT  ,10H          ,10H          ,HEDA0095
     110H          ,10H ,I3,F6.3))                                      HEDA0096
      DATA EQWT( 1),EF( 1),FC( 1),FH( 1),FN( 1),FO( 1),FA( 1)           HEDA0100
     1    /1.00,   -78.40, .370,  .022,  .185,  .423,  .000/            HEDA0110
      DATA((NAME( 2,I),I=1,5)=10H(37H TNETB,10H          ,10H          ,HEDA0115
     110H          ,10H ,I3,F6.3))                                      HEDA0116
      DATA EQWT( 2),EF( 2),FC( 2),FH( 2),FN( 2),FO( 2),FA( 2)           HEDA0120
     1    /1.13,   -307.1, .186,  .017,  .217,  .580,  .000/            HEDA0130
      DATA((NAME( 3,I),I=1,5)=10H(37H EXPLO,10HSIVE D    ,10H          ,HEDA0135
     110H          ,10H ,I3,F6.3))                                      HEDA0136
      DATA EQWT( 3),EF( 3),FC( 3),FH( 3),FN( 3),FO( 3),FA( 3)           HEDA0140
     1    /0.85,   -386.3, .293,  .025,  .227,  .455,  .000/            HEDA0150
      DATA((NAME( 4,I),I=1,5)=10H(37H PENTO,10HLITE (PETN,10H/TNT,50/50,HEDA0155
     110H)         ,10H ,I3,F6.3))                                      HEDA0156
      DATA EQWT( 4),EF( 4),FC( 4),FH( 4),FN( 4),FO( 4),FA( 4)           HEDA0160
     1    /1.17,   -242.8, .280,  .024,  .182,  .514,  .000/            HEDA0170
      DATA((NAME( 5,I),I=1,5)=10H(37H PICRA,10HTOL (EXPLO,10HSIVE D/TNT,HEDA0175
     110H52/48)    ,10H ,I3,F6.3))                                      HEDA0176
      DATA EQWT( 5),EF( 5),FC( 5),FH( 5),FN( 5),FO( 5),FA( 5)           HEDA0180
     1    /0.90,   -238.5, .329,  .024,  .207,  .440,  .000/            HEDA0190
      DATA((NAME( 6,I),I=1,5)=10H(37H CYCLO,10HTOL (RDX/T,10HNT,70/30) ,HEDA0195
     110H          ,10H ,I3,F6.3))                                      HEDA0196
      DATA EQWT( 6),EF( 6),FC( 6),FH( 6),FN( 6),FO( 6),FA( 6)           HEDA0200
     1    /1.14,    22.79, .225,  .026,  .320,  .429,  .000/            HEDA0210
      DATA((NAME( 7,I),I=1,5)=10H(37H COMP ,10HB (RDX/TNT,10H/WAX,59.4/,HEDA0215
     110H39.6/1.0) ,10H ,I3,F6.3))                                      HEDA0216
      DATA EQWT( 7),EF( 7),FC( 7),FH( 7),FN( 7),FO( 7),FA( 7)           HEDA0220
     1    /1.10,     4.33, .252,  .026,  .298,  .424,  .000/            HEDA0230
      DATA((NAME( 8,I),I=1,5)=10H(37H RDX/W,10HAX, 98/2  ,10H          ,HEDA0235
     110H          ,10H ,I3,F6.3))                                      HEDA0236
      DATA EQWT( 8),EF( 8),FC( 8),FH( 8),FN( 8),FO( 8),FA( 8)           HEDA0240
     1    /1.19,    57.00, .176,  .030,  .371,  .423,  .000/            HEDA0250
      DATA((NAME( 9,I),I=1,5)=10H(37H COMP ,10HA-3 (RDX/W,10HAX,91/9)  ,HEDA0255
     110H          ,10H ,I3,F6.3))                                      HEDA0256
      DATA EQWT( 9),EF( 9),FC( 9),FH( 9),FN( 9),FO( 9),FA( 9)           HEDA0260
     1    /1.09,    24.93, .225,  .038,  .344,  .393,  .000/            HEDA0270
      DATA((NAME(10,I),I=1,5)=10H(37H TNETB,10H/AL, 90/10,10H          ,HEDA0275
     110H          ,10H ,I3,F6.3))                                      HEDA0276
      DATA EQWT(10),EF(10),FC(10),FH(10),FN(10),FO(10),FA(10)           HEDA0280
     1    /1.23,   -276.4, .168,  .014,  .196,  .522,  .100/            HEDA0290
      DATA((NAME(11,I),I=1,5)=10H(37H TNETB,10H/AL, 78/22,10H          ,HEDA0295
     110H          ,10H ,I3,F6.3))                                      HEDA0296
      DATA EQWT(11),EF(11),FC(11),FH(11),FN(11),FO(11),FA(11)           HEDA0300
     1    /1.18,   -239.5, .146,  .012,  .170,  .452,  .220/            HEDA0310
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      DATA((NAME(12,I),I=1,5)=10H(37H TNETB,10H/AL, 72/28,10H              ,HEDA0315
     110H          ,10H ,I3,F6.3))                                          HEDA0316
      DATA EQWT(12),EF(12),FC(12),FH(12),FN(12),FO(12),FA(12)              HEDA0320
     1   /1.18,   -221.1, .134,  .011,  .157,  .418,  .280/                HEDA0330
      DATA((NAME(13,I),I=1,5)=10H(37H TNETB,10H/AL, 65/35,10H              ,HEDA0335
     110H          ,10H ,I3,F6.3))                                          HEDA0336
      DATA EQWT(13),EF(13),FC(13),FH(13),FN(13),FO(13),FA(13)              HEDA0340
     1   /1.23,   -199.6, .121,  .010,  .142,  .377,  .350/                HEDA0350
      DATA((NAME(14,I),I=1,5)=10H(37H TRITO,10HNAL (TNT/A,10HL,80/20)     ,HEDA0355
     110H          ,10H ,I3,F6.3))                                          HEDA0356
      DATA EQWT(14),EF(14),FC(14),FH(14),FN(14),FO(14),FA(14)              HEDA0360
     1   /1.07,   -62.72, .296,  .018,  .148,  .338,  .200/                HEDA0370
      DATA((NAME(15,I),I=1,5)=10H(37H RDX/A,10HL/WAX, 88/,10H10/2          ,HEDA0375
     110H          ,10H ,I3,F6.3))                                          HEDA0376
      DATA EQWT(15),EF(15),FC(15),FH(15),FN(15),FO(15),FA(15)              HEDA0380
     1   /1.30,    50.38, .160,  .027,  .333,  .380,  .100/                HEDA0390
      DATA((NAME(16,I),I=1,5)=10H(37H RDX/A,10HL/WAX, 78/,10H20/2          ,HEDA0395
     110H          ,10H ,I3,F6.3))                                          HEDA0396
      DATA EQWT(16),EF(16),FC(16),FH(16),FN(16),FO(16),FA(16)              HEDA0400
     1   /1.32,    43.76, .144,  .024,  .295,  .337,  .200/                HEDA0410
      DATA((NAME(17,I),I=1,5)=10H(37H RDX/A,10HL/WAX, 74/,10H21/5          ,HEDA0415
     110H          ,10H ,I3,F6.3))                                          HEDA0416
      DATA EQWT(17),EF(17),FC(17),FH(17),FN(17),FO(17),FA(17)              HEDA0420
     1   /1.30,    29.36, .163,  .027,  .280,  .320,  .210/                HEDA0430
      DATA((NAME(18,I),I=1,5)=10H(37H RDX/A,10HL/WAX, 74/,10H22/4          ,HEDA0435
     110H          ,10H ,I3,F6.3))                                          HEDA0436
      DATA EQWT(18),EF(18),FC(18),FH(18),FN(18),FO(18),FA(18)              HEDA0440
     1   /1.30,    33.28, .154,  .026,  .280,  .320,  .220/                HEDA0450
      DATA((NAME(19,I),I=1,5)=10H(37H RDX/A,10HL/WAX, 62/,10H33/5          ,HEDA0455
     110H          ,10H ,I3,F6.3))                                          HEDA0456
      DATA EQWT(19),EF(19),FC(19),FH(19),FN(19),FO(19),FA(19)              HEDA0460
     1   /1.19,    21.42, .143,  .024,  .235,  .268,  .330/                HEDA0470
      DATA((NAME(20,I),I=1,5)=10H(37H TORPE,10HX II (RDX/,10HTNT/AL,42/,HEDA0475
     110H40/18)    ,10H ,I3,F6.3))                                          HEDA0476
      DATA EQWT(20),EF(20),FC(20),FH(20),FN(20),FO(20),FA(20)              HEDA0480
     1   /1.24,    -3.57, .216,  .021,  .233,  .350,  .180/                HEDA0490
      DATA((NAME(21,I),I=1,5)=10H(37H H-6 (,10HRDX/TNT/AL,10H/WAX,45/29,HEDA0495
     110H/21/5)    ,10H ,I3,F6.3))                                          HEDA0496
      DATA EQWT(21),EF(21),FC(21),FH(21),FN(21),FO(21),FA(21)              HEDA0500
     1   /1.27,   -12.56, .223,  .025,  .224,  .318,  .210/                HEDA0510
      DATA((NAME(22,I),I=1,5)=10H(37H HBX-1,10H (RDX/TNT/,10HAL/WAX,40/,HEDA0515
     110H38/17/5)  ,10H ,I3,F6.3))                                          HEDA0516
      DATA EQWT(22),EF(22),FC(22),FH(22),FN(22),FO(22),FA(22)              HEDA0520
     1   /1.21,   -22.93, .249,  .026,  .221,  .334,  .170/                HEDA0530
      DATA((NAME(23,I),I=1,5)=10H(37H HBX-3,10H (RDX/TNT/,10HAL/WAX,31/,HEDA0535
     110H29/35/5)  ,10H ,I3,F6.3))                                          HEDA0536
      DATA EQWT(23),EF(23),FC(23),FH(23),FN(23),FO(23),FA(23)              HEDA0540
     1   /1.16,   -21.83, .200,  .022,  .171,  .257,  .350/                HEDA0550
      DATA((NAME(24,I),I=1,5)=10H(37H TNETB,10H/RDX/AL, 3,10H9/26/35      ,HEDA0555
     110H          ,10H ,I3,F6.3))                                          HEDA0556
      DATA EQWT(24),EF(24),FC(24),FH(24),FN(24),FO(24),FA(24)              HEDA0560
     1   /1.24,   -102.6, .115,  .013,  .184,  .338,  .350/                HEDA0570
      DATA((NAME(25,I),I=1,5)=10H(37H ALUMI,10HNUM       ,10H              ,HEDA0575
     110H          ,10H ,I3,F6.3))                                          HEDA0576
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 DATA EQWT(25),EF(25),FC(25),FH(25),FN(25),FO(25),FA(25)             HEDA0580
1   / 0.,      0.,   0.,    0.,    0.,    0.,    1./                 HEDA0590
 DATA((NAME(26,I),I=1,5)=10H(37H WAX  ,10H          ,10H            ,HEDA0595
110H        ,10H ,I3,F6.3))                                          HEDA0596
 DATA EQWT(26),EF(26),FC(26),FH(26),FN(26),FO(26),FA(26)             HEDA0600
1   / 0.,    -392., .856,  .144,   0.,    0.,    0./                 HEDA0610
 DATA((NAME(27,I),I=1,5)=10H(37H RDX  ,10H          ,10H            ,HEDA0615
110H        ,10H ,I3,F6.3))                                          HEDA0616
 DATA EQWT(27),EF(27),FC(27),FH(27),FN(27),FO(27),FA(27)             HEDA0620
1   / 0.,     66.16, .162,  .027,  .379,  .432,   0./                HEDA0630
 DATA((NAME(28,I),I=1,5)=10H(37H PETN ,10H          ,10H            ,HEDA0635
110H        ,10H ,I3,F6.3))                                          HEDA0636
 DATA EQWT(28),EF(28),FC(28),FH(28),FN(28),FO(28),FA(28)             HEDA0640
1   / 0.,    -407.1, .190,  .026,  .177,  .607,   0./                HEDA0650
 DATA((NAME(29,I),I=1,5)=10H(37H TETRY,10HL         ,10H            ,HEDA0655
110H        ,10H ,I3,F6.3))                                          HEDA0656
 DATA EQWT(29),EF(29),FC(29),FH(29),FN(29),FO(29),FA(29)             HEDA0660
1   / 0.,     16.26, .293,  .017,  .244,  .446,   0./                HEDA0670
 DATA((NAME(30,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0675
110H        ,10H ,I3,F6.3))                                          HEDA0676
 DATA EQWT(30),EF(30),FC(30),FH(30),FN(30),FO(30),FA(30)             HEDA0680
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0690
 DATA((NAME(31,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0695
110H        ,10H ,I3,F6.3))                                          HEDA0696
 DATA EQWT(31),EF(31),FC(31),FH(31),FN(31),FO(31),FA(31)             HEDA0700
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0710
 DATA((NAME(32,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0715
110H        ,10H ,I3,F6.3))                                          HEDA0716
 DATA EQWT(32),EF(32),FC(32),FH(32),FN(32),FO(32),FA(32)             HEDA0720
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0730
 DATA((NAME(33,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0735
110H        ,10H ,I3,F6.3))                                          HEDA0736
 DATA EQWT(33),EF(33),FC(33),FH(33),FN(33),FO(33),FA(33)             HEDA0740
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0750
 DATA((NAME(34,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0755
110H        ,10H ,I3,F6.3))                                          HEDA0756
 DATA EQWT(34),EF(34),FC(34),FH(34),FN(34),FO(34),FA(34)             HEDA0760
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0770
 DATA((NAME(35,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0775
110H        ,10H ,I3,F6.3))                                          HEDA0776
 DATA EQWT(35),EF(35),FC(35),FH(35),FN(35),FO(35),FA(35)             HEDA0780
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0790
 DATA((NAME(36,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0795
110H        ,10H ,I3,F6.3))                                          HEDA0796
 DATA EQWT(36),EF(36),FC(36),FH(36),FN(36),FO(36),FA(36)             HEDA0800
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0810
 DATA((NAME(37,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0815
110H        ,10H ,I3,F6.3))                                          HEDA0816
 DATA EQWT(37),EF(37),FC(37),FH(37),FN(37),FO(37),FA(37)             HEDA0820
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0830
 DATA((NAME(38,I),I=1,5)=10H          ,10H          ,10H            ,HEDA0835
110H        ,10H ,I3,F6.3))                                          HEDA0836
 DATA EQWT(38),EF(38),FC(38),FH(38),FN(38),FO(38),FA(38)             HEDA0840
1   / 0.,      0.,   0.,    0.,    0.,    0.,    0./                 HEDA0850
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      DATA((NAME(39,I),I=1,5)=10H           ,10H           ,10H          ,HEDA0855
     110H          ,10H ,I3,F6.3))                                       HEDA0856
      DATA EQWT(39),EF(39),FC(39),FH(39),FN(39),FO(39),FA(39)            HEDA0860
     1    /  0.,       0.,   0.,     0.,     0.,     0.,     0./         HEDA0870
      DATA((NAME(40,I),I=1,5)=10H           ,10H           ,10H          ,HEDA0875
     110H          ,10H ,I3,F6.3))                                       HEDA0876
      DATA EQWT(40),EF(40),FC(40),FH(40),FN(40),FO(40),FA(40)            HEDA0880
     1    /  0.,       0.,   0.,     0.,     0.,     0.,     0./         HEDA0890
C                                                                        HEDA0990
      IF(NUMBER.EQ.-1) GO TO 1200                                        HEDA0995
      N=NUMBER   $WFACT=EQWT(N)   $EFORM=EF(N)/1000.                     HEDA1000
C WEIGHT FRACTIONS                                                       HEDA1010
      WFC=FC(N)   $WFH=FH(N)   $WFN=FN(N)   $WFO=FO(N)   $WFA=FA(N)      HEDA1020
      DO 1030 L=1,5                                                      HEDA1025
 1030 NAMES(L)=NAME(N,L)   $PRINT NAMES                                  HEDA1030
      RETURN                                                             HEDA1050
C                                                                        HEDA1190
C MIX UP AN EXPLOSIVE FROM COMPONENTS IN LIST.                           HEDA1195
 1200 EFORM=WFC=WFH=WFN=WFO=WFA=0.   $PRINT 1370                         HEDA1200
      DO 1290 I=1,9   $N=NUMHE(I)   $HF=HEFRAC(I)                        HEDA1210
      IF(N.EQ.0) GO TO 1300                                              HEDA1220
      DO 1225 L=1,5                                                      HEDA1222
 1225 NAMES(L)=NAME(N,L)   $PRINT NAMES,N,HF                             HEDA1225
      EFORM=EFORM+HF*EF(N)   $WFC=WFC+HF*FC(N)                           HEDA1230
      WFH=WFH+HF*FH(N)   $WFN=WFN+HF*FN(N)                               HEDA1240
      WFO=WFO+HF*FO(N)   $WFA=WFA+HF*FA(N)                               HEDA1250
 1290 CONTINUE                                                           HEDA1290
 1300 EFORM=EFORM/1000.   $RETURN                                        HEDA1300
 1370 FORMAT(*0MAKE UP SPECIAL HE MIXTURE--*/                            HEDA1370
     1* NAME*,29X,*NUMBER  WT FRAC*)                                     HEDA1375
      END                                                                HEDA1400
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      SUBROUTINE GAMMA(T,G,U)
      COMMON/MOLGAS/MO2,MN2,MCO,MCO2,MH2O,MH2
      REAL MO2,MN2,MCO,MCO2,MH2O,MH2
C MO2 ETC ARE LB MOLES BUT UNITS CANCEL HERE.
      U2=5.76+20./T**.5+.000578*T
      U4=11.515-172./T**.5+1530./T
      U6=9.47-3470./T+1160000./T**2
      U8=19.86-597./T**.5+7500./T
      U9=9.46-3290./T+1070000./T**2
      U1=16.2-6530./T+1410000./T**2
      U=U2*MH2+U4*MO2+U6*MN2+U8*MH2O+U9*MCO+U1*MCO2
      U=U/(MH2+MO2+MN2+MH2O+MCO+MCO2)
      G=U/(U-1.987)
      RETURN
      END
```

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      SUBROUTINE GASES(V,AIRMOL,P2,G,TR)                                GAS 0010
C INPUT DATA ARE NPRINT,V,AIRMOL,WC,WH,WN,WO,WA.                         GAS 0020
C OUTPUT DATA ARE P2,G,TR,Q,MO2,MN2,MCO,MCO2,MH2O,MH2.                  GAS 0030
C V=CHAMBER VOLUME (CU FT).                                             GAS 0040
C AIRMOL=LB MOLES OF AIR IN CHAMBER.                                    GAS 0050
C P2=OVERPRESSURE IN CHAMBER DUE TO HE GASES (PSI).                     GAS 0060
C G=SPECIFIC HEAT RATIO OF HE GAS-AIR MIXTURE IN CHAMBER.               GAS 0070
C TR=TEMPERATURE (RANKINE).                                             GAS 0080
C     STATIC CHAMBER PRESSURE CALCULATION ACCOUNTING FOR AVAILABLE O2.  GAS 0090
C     COMBUSTION PRODUCT SEQUENCE IS H2O, AL2O3, CO, CO2.               GAS 0100
      COMMON/DATA1/WLB,NUMBER,RLOD,CASE,VINIT,AINIT,PAMB,TAMB,ALTKFT,   GAS 0110
     1 PCHAM,TCHAM,NOPT,NV,NR, WFACT,EFORM                              GAS 0120
      COMMON/MOLGAS/MO2,MN2,MCO,MCO2,MH2O,MH2                           GAS 0130
      COMMON/HEMASS/WC,WH,WN,WO,WA                                      GAS 0140
      COMMON/GAS/N1,N2,N3,N4,N5,N6,N7,                                  GAS 0150
     1 M1,M2,M3,M4,M5,M6,M7,M8,M9, R,Q,X2                               GAS 0160
      REAL N1,N2,N3,N4,N5,N6,N7                                         GAS 0170
      REAL M1,M2,M3,M4,M5,M6,M7,M8,M9                                   GAS 0180
      REAL MO2,MN2,MCO,MCO2,MH2O,MH2                                    GAS 0190
      PRINT 210                                                         GAS 0200
  210 FORMAT(*0PROPERTIES OF GASES--*)                                  GAS 0210
      Q=R=M2=M5=M7=M8=M9=M1=0.                                          GAS 0220
C GRAM MOLES C,H2,N2,O2,AL2                                             GAS 0230
      N1=WC*453.6/12.                                                   GAS 0240
      N2=WH*453.6/2.                                                    GAS 0250
      N3=WN*453.6/28.                                                   GAS 0260
      N4=WO*453.6/32.                                                   GAS 0270
      N5=WA*453.6/53.963                                                GAS 0280
      N6=N3+.7905*AIRMOL*453.6                                          GAS 0290
      N7=N4+.2095*AIRMOL*453.6                                          GAS 0300
C R=GMOLES O2 LEFT.                                                     GAS 0310
      R=N7-N2/2.    $IF(R.GT.0.) GO TO 340                              GAS 0320
      M8=2.*(R+N2/2.)   $M2=N2-M8   $R=0.   $Q=57.80*M8   $GO TO 450    GAS 0330
  340 M8=N2   $Q=N2*57.80   $R=R-1.5*N5   $IF(R.GT.0.) GO TO 370        GAS 0340
      M5=(R+1.5*N5)*(2./3.)   $Q=Q+M5*400.3   $R=0.   $GO TO 430        GAS 0350
  370 Q=Q+N5*400.3   $R=R-N1   $IF(R.GT.0.) GO TO 510                   GAS 0370
      R=R+N1/2.   $IF(R.GT.0.) GO TO 420                                GAS 0400
      M9=2.*(R+N1/2.)   $Q=Q+M9*26.42   $R=0.   $GO TO 470              GAS 0410
  420 M1=2.*R   $M9=N1-2.*R   $Q=Q+M1*94.05+M9*26.42   $R=0.   $GO TO 490GAS 0420
  430 RESULT=M5/N5   $PRINT 440,RESULT   $GO TO 540                     GAS 0430
  440 FORMAT(* PERCENT LAST PRODUCT (AL2O3) =* G12.5)                   GAS 0440
  450 RESULT=M2/N2   $PRINT 460,RESULT   $GO TO 540                     GAS 0450
  460 FORMAT(* PERCENT LAST PRODUCT (H2O)   =* G12.5)                   GAS 0460
  470 RESULT=M9/N1   $PRINT 480,RESULT   $GO TO 540                     GAS 0470
  480 FORMAT(* PERCENT LAST PRODUCT (CO)    =* G12.5)                   GAS 0480
  490 RESULT=M1/N1   $PRINT 500,RESULT   $GO TO 540                     GAS 0490
  500 FORMAT(* PERCENT LAST PRODUCT (CO2)   =* G12.5)                   GAS 0500
  510 PRINT 520                                                         GAS 0510
  520 FORMAT(* OXIDATION COMPLETE*)                                     GAS 0520
      M1=N1   $Q=Q+94.05*N1                                             GAS 0530
  540 X2=R+M2+N6+M8+M9+M1                                               GAS 0540
      X3=X2-AIRMOL*453.6                                                GAS 0550
      Q=Q+.592*X3                                                       GAS 0560
C     Q=ENERGY RELEASED (KCAL).                                         GAS 0570
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      Q=Q+WLB*453.6*EFORM                                               GAS 0580
C LB MOLES OF GASES.                                                    GAS 0600
      MO2=R/453.6   $MN2=N6/453.6   $MCO=M9/453.6   $MCO2=M1/453.6      GAS 0610
      MH2O=M8/453.6   $MH2=M2/453.6                                     GAS 0620
      DT=100.   $Q1=0.   $U=7.   $T=1.8*(TCHAM+273.16)                  GAS 0630
C INTEGRATE UNTIL T IS FOUND SO ENERGY EQUALS Q.                        GAS 0640
      DO 760 J=1,100   $T=T+DT                                          GAS 0650
      CALL GAMMA(T,G,U)   $DQ=(U-1.987)*DT*X2*.0005556                  GAS 0660
      Q1=Q1+DQ   $IF(Q1.GE.Q) GO TO 780                                 GAS 0750
  760 CONTINUE   $PRINT 770                                             GAS 0760
  770 FORMAT(* T HAS REACHED UPPER LIMIT.*)                             GAS 0770
C CORRECT T SO Q1 HITS Q EXACTLY.                                       GAS 0775
  780 T=T-(Q1-Q)/DQ*DT   $G=U/(U-1.987)                                 GAS 0780
C ABSOLUTE PRESSURE (PSIA)                                              GAS 0785
      P2=X2/453.6*1.987*778./144. *T/V   $TR=T   $P2=P2-PCHAM           GAS 0790
      TF=T-460.   $PRINT 810,TF                                         GAS 0800
  810 FORMAT(* TEMPERATURE, DEGREES F  =*G12.5)                         GAS 0810
      QPERG=Q/(453.6*WLB)   $PRINT 814,QPERG                            GAS 0812
  814 FORMAT(* ENERGY RELEASE(KCAL/G)  =*G12.5)                         GAS 0814
      PRINT 830,G                                                       GAS 0820
  830 FORMAT(* SPECIFIC HEAT RATIO     =*G12.5)                         GAS 0830
      PRINT 870,P2                                                      GAS 0860
  870 FORMAT(* GAS OVERPRESSURE(PSI)   =*G12.5)                         GAS 0870
      RETURN                                                            GAS 0880
      END                                                               GAS 0890
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      SUBROUTINE TNT(L)
C POSITIVE-PHASE PROPERTIES FOR 1 LB TNT IN SEA-LEVEL AIR.
      COMMON/TNTIN/RTNT,KMAX1
      COMMON/TNTOUT/PTNT,TSTNT,TPTNT,TCTNT,PCTNT,PSI(40),T1(40),T2(40)
     1,JJ,XIMP1
      DIMENSION P(108),R(108),TS(108),TP(108),TC(23)
C RADIAL DISTANCE FROM CHARGE CENTER (CM).
      DATA R/  4.054,   4.680,   5.700,   7.120,   9.200,   10.6,    12.4,
     1   14.7,    17.6,    19.0,    21.7,    25.0,    28.1,    30.0,    32.0,
     2   34.5,    37.4,    41.0,    46.0,    48.8,    52.4,    57.3,    65.,
     3   66.4,    72.0,    79.0,    85.3,    89.0,    93.0,    98.4,    105.,
     4   114.,    125.,    133.,    142.,    154.,    171.,    180.,    196.,
     5   218.,    230.,    251.,    269.,    289.,    316.,    350.,    402.,
     6   438.,    483.,    546.,    640.,    688.,    781.,    920.,    1070.,
     7  1160.,   1260.,   1400.,   1580.,   1830.,   2200.,   2450.,   2790.,
     8  3220.,   3900.,   4250.,   4960.,   6010.,   7030.,   7710.,   8540.,
     9  9600.,1.10E+4,1.29E+4,1.57E+4,1.77E+4,2.04E+4,2.40E+4,2.92E+4,
     13.21E+4,3.79E+4,4.64E+4,5.48E+4,6.04E+4,6.73E+4,7.60E+4,8.76E+4,
     1103600.,127400.,144200.,166400.,197100.,242700.,267800.,317600.,
     2391300.,464300.,512500.,572500.,649100.,750400.,891100.,1.10E+6,
     31.248E6,1.444E6,1.716E6,2.120E6,2.342E6/
C INCIDENT OVERPRESSURE (PSI).
      DATA P/  7800.,   7000.,   6000.,   5000.,   4000.,   3500.,   3000.,
     1  2500.,   2000.,   1800.,   1500.,   1200.,   1000.,   900.,    800.,
     2   700.,    600.,    500.,    400.,    350.,    300.,    250.,    190.,
     3   180.,    150.,    120.,    100.,     90.,     80.,     70.,     60.,
     4    50.,     40.,     35.,     30.,     25.,     20.,     18.,     15.,
     5    12.,     10.,    9.0,     8.0,     7.0,     6.0,     5.0,     4.0,
     6    3.5,     3.0,    2.5,     2.0,     1.8,     1.5,     1.2,     1.0,
     7    .90,     .80,    .70,     .60,     .50,     .40,     .35,     .30,
     8    .25,     .20,    .18,     .15,     .12,     .10,     .09,     .08,
     9    .07,     .06,    .05,     .04,    .035,     .03,    .025,     .02,
     1   .018,    .015,   .012,    .010,    .009,    .008,    .007,    .006,
     1   .005,    .004,  .0035,    .003,   .0025,    .002,   .0018,   .0015,
     2  .0012,   .0010,  .0009,   .0008,   .0007,   .0006,   .0005,   .0004,
     3 .00035,   .0003, .00025,   .0002,  .00018/
C SHOCK FRONT ARRIVAL TIME (SEC).
      DATA TS/ 1.E-10, .78E-6,2.25E-6,4.52E-6,8.30E-6,10.9E-6,14.8E-6,
     120.0E-6,27.4E-6,31.3E-6,39.3E-6,49.9E-6,60.7E-6,68.3E-6,76.2E-6,
     288.0E-6,100.E-6,113.E-6,146.E-6,163.E-6,186.E-6,220.E-6,281.E-6,
     3293.E-6,343.E-6,410.E-6,479.E-6,517.E-6,564.E-6,629.E-6,714.E-6,
     4840.E-6,1.01E-3,1.14E-3,1.30E-3,1.51E-3,1.84E-3,2.02E-3,2.36E-3,
     52.84E-3,3.32E-3,3.58E-3,4.04E-3,4.52E-3,5.19E-3,6.06E-3,7.40E-3,
     68.38E-3,9.59E-3,11.3E-3,13.9E-3,15.2E-3,17.8E-3,21.7E-3,26.0E-3,
     7  .0286,   .0315,   .0355,   .0407,   .0479,   .0587,   .0659,   .0758,
     8  .0884,   .1082,   .1185,   .1392,   .1700,   .1998,   .2198,   .2438,
     9  .2746,   .3157,   .3714,   .4536,   .5123,   .5916,   .6973,   .8500,
     1  .9352,   1.106,   1.355,   1.602,   1.766,   1.969,   2.225,   2.566,
     1  3.036,   3.735,   4.229,   4.881,   5.783,   7.123,   7.861,   9.324,
     2  11.49,   13.64,   15.05,   16.81,   19.06,   22.04,   26.18,   32.32,
     3  36.66,   42.42,   50.42,   62.29,   68.81/
C DURATION OF POSITIVE OVERPRESSURE (SEC).
C FIRST 23 VALUES ARE DURATION IF CONTACT SURFACE HAD NOT ARRIVED.
      DATA TP/3.90E-5,4.30E-5,5.00E-5,5.90E-5,7.20E-5,8.00E-5,9.00E-5,
     11.02E-4,1.19E-4,1.28E-4,1.41E-4,1.60E-4,1.76E-4,1.86E-4,1.98E-4,
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     22.10E-4,2.27E-4,2.45E-4,2.74E-4,2.89E-4,3.08E-4,3.35E-4,3.80E-4,  TNT 0560
     33.88E-4,4.20E-4,4.70E-4, .50E-3, .52E-3, .55E-3, .58E-3, .62E-3,  TNT 0570
     4 .68E-3, .76E-3, .83E-3, .90E-3, .99E-3,1.12E-3,1.19E-3,1.29E-3,  TNT 0580
     51.41E-3,1.51E-3,1.57E-3,1.65E-3,1.78E-3,1.84E-3,1.96E-3,2.13E-3,  TNT 0590
     62.24E-3,2.36E-3,2.52E-3,2.72E-3,2.82E-3,3.00E-3,3.17E-3,3.32E-3,  TNT 0600
     73.39E-3,3.45E-3,3.54E-3,3.62E-3,3.72E-3,3.84E-3,3.90E-3,3.97E-3,  TNT 0610
     84.05E-3,4.15E-3,4.19E-3,4.25E-3,4.34E-3,4.40E-3,4.45E-3,4.49E-3,  TNT 0620
     94.52E-3,     0.,     0.,     0.,     0.,     0.,     0.,     0.,  TNT 0630
     1 0.,0.,0.,0.,0.,0.,0.,0., 0.,0.,0.,0.,0.,0.,0.,                   TNT 0640
     1 0.,0.,0.,0.,0.,0.,0.,0., 0.,0.,0.,0.,0./                         TNT 0650
C TIME (SEC) BETWEEN SHOCK FRONT AND CONTACT SURFACE ARRIVAL.           TNT 0660
      DATA TC/ 1.E-10,  .1E-6, .24E-6, .46E-6, .80E-6,1.10E-6, 1.5E-6,  TNT 0670
     12.24E-6, 3.3E-6,3.95E-6, 5.2E-6, 7.5E-6,10.9E-6,13.2E-6,15.9E-6,  TNT 0680
     220.2E-6,26.2E-6, 34.E-6, 49.E-6, 58.E-6, 77.E-6,116.E-6,452.E-6/  TNT 0690
C                                                                       TNT 0740
C     T1=TIME, T2=TIME SINCE SHOCK ARRIVAL.                             TNT 0750
      FUN1(X1,X2)=EXP(ALOG(X1)+FRAC*ALOG(X2/X1))                        TNT 0760
      XIMP1=TCTNT=0.                                                    TNT 0770
C FIND DESIRED POINT IN TABLES.                                         TNT 0780
      DO 810 JJ=2,108                                                   TNT 0790
      IF(RTNT.LT.R(JJ)) GO TO 830                                       TNT 0800
  810 CONTINUE    $JJ=108                                               TNT 0810
C DESIRED DATA LIES BETWEEN R(JJ-1) AND R(JJ).                          TNT 0820
  830 FRAC=ALOG(RTNT/R(JJ-1))/ALOG(R(JJ)/R(JJ-1))                       TNT 0830
      PTNT=FUN1(P(JJ-1),P(JJ))    $PSI(1)=PTNT                          TNT 0840
C CALC ONLY PSI(1) IF L=0 .                                             TNT 0850
      IF(L.EQ.0) RETURN                                                 TNT 0860
      TSTNT=FUN1(TS(JJ-1),TS(JJ))                                       TNT 0870
      TPTNT=FUN1(TP(JJ-1),TP(JJ))                                       TNT 0880
      IF(JJ.LE.23) TCTNT=FUN1(TC(JJ-1),TC(JJ))                          TNT 0890
C FIND SHAPE PARAMETER SIGMA.                                           TNT 0940
      SIGMA=228./RTNT-.95                                               TNT 0950
      IF(JJ.LE.23) SIGMA=228./65.-.95                                   TNT 0955
      T1(1)=TSTNT    $T2(1)=0.                                          TNT 0960
      PSI(KMAX1)=0.    $T1(KMAX1)=TSTNT+TPTNT    $T2(KMAX1)=TPTNT       TNT 0970
      DO 1030 K=2,KMAX1    $IF(K.EQ.KMAX1) GO TO 1020                   TNT 0980
      TAU=FLOAT(K)/FLOAT(KMAX1)                                         TNT 0990
      PI=(1.-TAU)*EXP(-TAU*(1.+SIGMA/(.5+TAU)))                         TNT 1000
      PSI(K)=PTNT*PI    $T2(K)=TAU*TPTNT    $T1(K)=TSTNT+T2(K)          TNT 1010
 1020 XIMP1=XIMP1+.5*(PSI(K)+PSI(K-1))*(T2(K)-T2(K-1))                  TNT 1020
 1030 CONTINUE    $RETURN                                               TNT 1030
      END                                                               TNT 1330
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      SUBROUTINE ARDC(ALTKFT,PAMB,TAMB)
C     ALTKFT=ALTITUDE (KILOFEET).
C     PAMB=AMBIENT PRESSURE (PSI).
C     TAMB=AMBIENT TEMPERATURE (C).
C
      ALTZ=ALTKFT*.3048E3  $ALTH=6356766.0*ALTZ/(6356766.0+ALTZ)
      IF(ALTH.GT.11000.) GO TO 100
      TEMP=288.16-0.0065*ALTH
      PAMB=14.696178/(288.160/(288.160-0.0065*ALTH))**5.25612218$GOTO400
  100 IF(ALTH.GT.25000.) GO TO 130
      TEMP=216.66
      PAMB=3.28254528/(10.**(0.068483253E-3*(ALTH-11000.0)))   $GOTO 400
  130 IF(ALTH.GT.47000.) GO TO 170
      TEMP=216.66+0.003*(ALTH-25000.0)
      PAMB=0.36094654/((141.660+3.0E-3*ALTH)/216.66)**11.38826473
      GO TO 400
  170 IF(ALTH.GT.53000.) GO TO 200
      TEMP=282.66
      PAMB=0.0174686/(10.**(0.0524926823E-3*(ALTH-47000.0)))   $GOTO 400
  200 IF(ALTH.GT.79000.) GO TO 230
      TEMP=282.66-0.0045*(ALTH-53000.0)
      PAMB=8.40408E-3/((282.66/TEMP)**7.592176)   $GOTO 400
  230 IF(ALTH.GT.90000.) GO TO 260
      TEMP=165.66
      PAMB=1.46198E-4*EXP (-0.0341647942*(ALTH-79000.0)/165.66)$GOTO 400
  260 IF(ALTH.GT.105000.) GO TO 290
      TEMP=165.66+0.0040*(ALTH-90000.0)
      PAMB=1.5519E-5*(165.66/TEMP)**8.541198    $GOTO 400
  290 IF(ALTH.GT.160000.) GO TO 320
      TEMP=225.66+0.02*(ALTH-105000.0)
      PAMB=1.04442E-6*(225.66/TEMP)**1.708239   $GOTO 400
  320 IF(ALTH.GT.170000.) GO TO 350
      TEMP=1325.66+0.01*(ALTH-160000.0)
      PAMB=5.14015E-8*(1325.66/TEMP)**3.4164794 $GOTO 400
  350 IF(ALTH.GT.200000.) GO TO 380
      TEMP=1425.66+0.005*(ALTH-170000.0)
      PAMB=4.0654E-8*(1425.66/TEMP)**6.832958   $GOTO 400
  380 TEMP=1575.66+0.0035*(ALTH-200000.0)
      PAMB=2.0595E-8*(1575.66/TEMP)**9.761369
  400 TAMB=TEMP-273.16   $RETURN
      END
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